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LIMITED INVESTIGATION OF THE EFFECTS OF ELEVATOR RATE LIMITING AND STICK DYNAMICS ON LONGITUDINAL PILOT INDUCED OSCILLATIONS (HAVE GRIP)

A F F T C

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FINAL REPORT

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This report presents the results of the HAVE GRIP flight test program. This program performed a limited investigation of the effects of stick dynamics and elevator rate limiting on longitudinal pilot induced oscillations (PIOs) and was performed as a Test Management Project as part of the Test Pilot School curriculum. The theoretical research behind this flight test was performed as part of an Air Force Institute of Technology thesis under the sponsorship of Wright Laboratory's Flight Control Division. The research and flight testing was sponsored by the Flight Control Division of Wright Laboratory. The first phase of this program investigated how elevator rate limiting affected the susceptibility to PIOs during offset landing tasks. The second phase investigated how variations in stick spring constant and natural frequency affected the PIO susceptibility of the system at a given elevator rate limit. The third phase investigated the combined effects of changing elevator rate limits with variations in stick spring constant and natural frequency.

14. SUBJECT TERMS

Elevator Rate Limiting	Stick Force Gradients	PIO
Flight Control Systems	Pilot Induced Oscillation	Rate Limited Actuators
Control Sticks	Control Stick Forces	Cooper-Harper Rating Scale
Handling Qualities		

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PREFACE

This report presents the results of the investigation of the HAVE GRIP flight test program into the effects of elevator rate limiting and aircraft stick dynamics on longitudinal pilot induced oscillations (PIOs). The theoretical research behind this flight test was performed as part of an Air Force Institute of Technology thesis under the sponsorship of Wright Laboratory's Flight Control Division.

The HAVE GRIP flight test project was conducted at Edwards AFB, California, by students of Test Pilot School Class 96A from 30 September to 11 October 1996 as part of the Test Management Phase Curriculum under job order number M96J0200.

The HAVE GRIP test team wishes to recognize the contributions of Mssrs. Russ Easter and Scott Buethe of CALSPAN. Their experience and willingness to share their knowledge with the test team were critical to the successful completion of this test program.

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EXECUTIVE SUMMARY

The HAVE GRIP flight test program was performed at the request of Wright Laboratories and as part of an Air Force Institute of Technology thesis. Based on this research, the hypothesis of the test was that, for a given pilot and flight condition, the difference between the elevator rate limit that caused divergent PIOs and that which caused undesired motions would be small (less than 10 degrees/second). It was also hypothesized that the PIO tendency caused by elevator rate limiting would decrease significantly with increased stick spring force constant and would decrease slightly with increased natural frequency of the stick. This test program was designed to test these hypotheses by evaluating PIOs in the offset landing task for a range of rate limits and stick characteristics.

The overall test objective was to investigate the effects of elevator rate limiting and stick dynamics on longitudinal pilot induced oscillations (PIO). The test was performed in three phases. The first phase identified the range of elevator rate limits to be used during Phases 2 and 3. The second phase identified the modified stick dynamics to be used in Phase 3. Phase 3 investigated the effects of elevator rate limiting and stick dynamics on PIOs during an offset landing task. All test objectives were met.

Testing was performed from 30 September to 11 October 1996 as part of the Test Management Phase of the USAF Test Pilot School curriculum. Testing involved multiple offset landings in the CALSPAN Variable Stability Learjet Model 25, registration number N102VS (Lear II), under contract to USAF Test Pilot School (TPS). Fifteen flights were performed in the Lear II, totaling 20.2 flight hours. The offset landings were performed at Air Force Plant 42, Palmdale, California. An additional two sorties in the T-38 (1.5 hours) and two sorties in the F-16 (3.2 hours) were flown prior to the start of testing to practice and refine the offset landing task.

There were three major conclusions. First, the offset landing task flown was insufficient to consistently uncover handling qualities deficiencies of the aircraft configuration flown. Second, rate limiting does not necessarily cause PIOs. At very low rate limits the problem was the lack of pitch response, not PIO. Any observed oscillations were very low frequency and small in amplitude. Third, for this configuration and task, variations in stick spring constant and natural frequency had negligible effect on the performance of the system with respect to assigned PIO and Cooper-Harper ratings. These conclusions are specific to this system and may not apply to all aircraft, especially aircraft where PIO tendencies are driven by much higher rate limits.

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INTRODUCTION

GENERAL

The purpose of this test was to investigate the effects of elevator rate limiting and stick dynamics on longitudinal pilot induced oscillations (PIO). This knowledge will help develop flight control systems less susceptible to PIOs caused by elevator rate limiting. Testing was performed in the CALSPAN Variable Stability Learjet Model 25, registration number N102VS (Lear II) under contract to USAF Test Pilot School (TPS).

Testing was requested by the Flight Control Division of Wright Laboratory and was conducted under the authority of USAF TPS. The responsible test organization (RTO) was USAF TPS, Edwards AFB, California. Flights were flown out of Edwards AFB with testing conducted at Air Force Plant 42, Palmdale, California, under USAF TPS Job Order Number M96J0200.

The scope of the program included 20.2 hours of flight time in 15 sorties in the Lear II. The number of sorties and flight time available limited the size of the test matrix. Two T-38 sorties (1.5 total hours) and two F-16B sorties (3.2 total hours) were flown for practice. The test program was executed from 30 September through 11 October 1996 at Edwards AFB, California. The limited investigation was conducted by students of USAF TPS Class 96A.

BACKGROUND

The effects of rate limiting and stick dynamics on the tendency of an aircraft to exhibit PIO are not fully understood. In order to develop updated standards for the next revision of MIL-STD-1797A (Reference 1), a better understanding of these interactions is required. The initial research to study this interaction was performed by Captain Patrick Peters, USAF TPS/EDA, for his Air Force Institute of Technology graduate thesis. Based on this research, the hypothesis of the test was that, for a given pilot and flight condition, the difference between the elevator rate limit that caused divergent PIOs and that which caused undesired motions would be small (less than 10 degrees/second). It was also hypothesized that the PIO tendency caused by elevator rate limiting would decrease significantly with increased stick spring force constant and would decrease slightly with increased natural frequency of the stick. This test program was designed to test these hypotheses by evaluating PIOs in the offset landing task for a range of rate limits and stick characteristics.

TEST ITEM DESCRIPTION

Test Aircraft:

The test aircraft was a Variable Stability Learjet Model 25, registration number N102VS (Lear II) operated by CALSPAN Corporation under contract with USAF TPS. The aircraft had been modified to serve as a three axis in-flight simulator. The center stick and side stick controllers replaced the standard right seat controls and controlled the aircraft through a fly-by-wire system. The aircraft's variable stability system (VSS), working through the fly-by-wire controls, enabled in-flight changes to the aircraft's stability and handling qualities. The VSS sensed the pilot's control inputs, summed these with the aircraft response signals, and, based on the programmed test flight control configuration, computed a signal that was sent to the hydraulic actuators that operated each control surface independently and in parallel with the normal Learjet actuating mechanisms. A detailed description of Lear II's VSS is contained in *Learjet Flight Syllabus and Background Material for the U.S Air Force/U.S. Navy Test Pilot School Variable Stability Programs* (Reference 2).

The left seat (safety pilot) controls were the original Learjet flight controls and allowed the left seat pilot to serve as a safety observer. Control inputs from the left controls were sent to the control surfaces through the normal Learjet mechanical flight control system; completely bypassing the VSS. Because the mechanical flight controls were reversible, the safety pilot could see the actual control surface movement by watching the yoke. The safety pilot could take control of the aircraft at any time by manually disengaging the VSS, this was accomplished by pressing any of the disengage

buttons located on the yoke, glare shield, and throttle quadrant, or by making a large force input on the yoke. Additionally, the VSS had embedded safety trips that would automatically disengage the VSS when the computer sensed aircraft motions and rates outside the predefined limits.

Test Flight Control System:

The pitch rate control system under test was various combinations of elevator rate limits and stick dynamics with simulated aircraft dynamics programmed into the Lear II. The basic aircraft dynamics for the test program were identified during Captain Peters' thesis research and were the same dynamics used in the HAVE PIO flight test program (Reference 3). A detailed description of the aircraft dynamics is contained in Appendix F. These dynamics were programmed into the Lear II and flown with successively decreased elevator rate limits and varied stick dynamics.

TEST OBJECTIVES

The overall test objective was to investigate the effects of elevator rate limiting and stick dynamics on longitudinal PIO. The test was conducted in three phases as discussed in the Test and Evaluation section of this report. The specific test objectives were to:

1. Establish the elevator rate limit to be used in Phase 2 and the three elevator rate limits to be used in Phase 3.

2. Establish two changes from the nominal stick dynamics to be used in Phase 3. One was a change in the spring constant and the other was a change in natural frequency.

3. Investigate the effects of stick dynamics on longitudinal PIO caused by elevator rate limiting.

4. Obtain flight test data for future investigations of rate limiting as a cause for PIO.

All test objectives were met.

LESSONS LEARNED

During the course of this flight test project, several lessons learned were identified and should be considered in future investigations of longitudinal PIOs caused by elevator rate limiting. A detailed discussion of these lessons learned are outlined in Appendix H.

TEST AND EVALUATION

GENERAL

The primary objective of the HAVE GRIP flight test program was to investigate the effects of elevator rate limiting and stick dynamics on longitudinal PIO. Specifically, the hypothesis of the test was that, for a given pilot and flight condition, the difference between the elevator rate limit that caused divergent PIOs and that which caused undesired motions would be small (less than 10 degrees/second). It was also hypothesized that the PIO tendency caused by elevator rate limiting would decrease significantly with an increased stick spring force constant and would decrease slightly with an increased natural frequency of the stick. This test program was designed to test these hypotheses by evaluating PIOs in the offset landing task for a range of rate limits and stick characteristics. The flight test program was conducted in three phases.

A portion of the test program was used to verify that the Lear II adequately simulated the desired aircraft dynamics (Appendix F).

Phase 1:

A single set of aircraft dynamics with the nominal stick defined in Appendix F was incorporated in the Lear II and flown with successively decreased elevator rate limits to determine which rate limits to use in the Phases 2 and 3. These rate limits were on the simulated aircraft's elevator, not the Lear II's elevator (Appendix F).

Phase 2:

The spring constant and natural frequency of the stick were varied independently and flown with a single elevator rate limit determined in Phase 1 in order to identify the two stick configurations to be used in Phase 3.

Phase 3:

Four elevator rate limits (200 degrees/second and the three rate limits determined in Phase 1) were flown with three stick configurations (nominal plus the two identified in Phase 2) to investigate the effects of elevator rate limiting and stick dynamics on longitudinal PIOs.

TEST PROCEDURES

Prior to the test missions, two T-38 and two F-16 practice sorties were flown against a marked runway (Figure 1) to acquaint the pilots with the offset landing task in a variety of aircraft with different landing handling qualities. These flights increased pilot proficiency in the offset landing task and thereby increased the quality of the test results.

When necessary, the stick natural frequency and force gradients were verified on the ground prior to taxiing. The test aircraft was flown directly from Edwards AFB to Air Force Plant 42, Palmdale, California. At 5,000 feet MSL the control system was engaged and several programmed test inputs (PTI) were input to verify the model. Two offset landing tasks were then flown as a warmup for the pilots. After the warmup landings were complete, the test configurations were set on downwind by the CALSPAN engineer onboard as directed by the test director. The rate limits were then verified by the real time elevator rate trace available in the aircraft. All offset landing tasks were setup visually with a 300-foot lateral offset, following the ILS glideslope down to 200 feet above ground level (AGL). At this point, a correction was made to land onspeed inside the desired box, painted on Runway 25 at Palmdale, with no lateral drift across the runway. Appendix E contains a complete description of the landing task and associated performance standards.

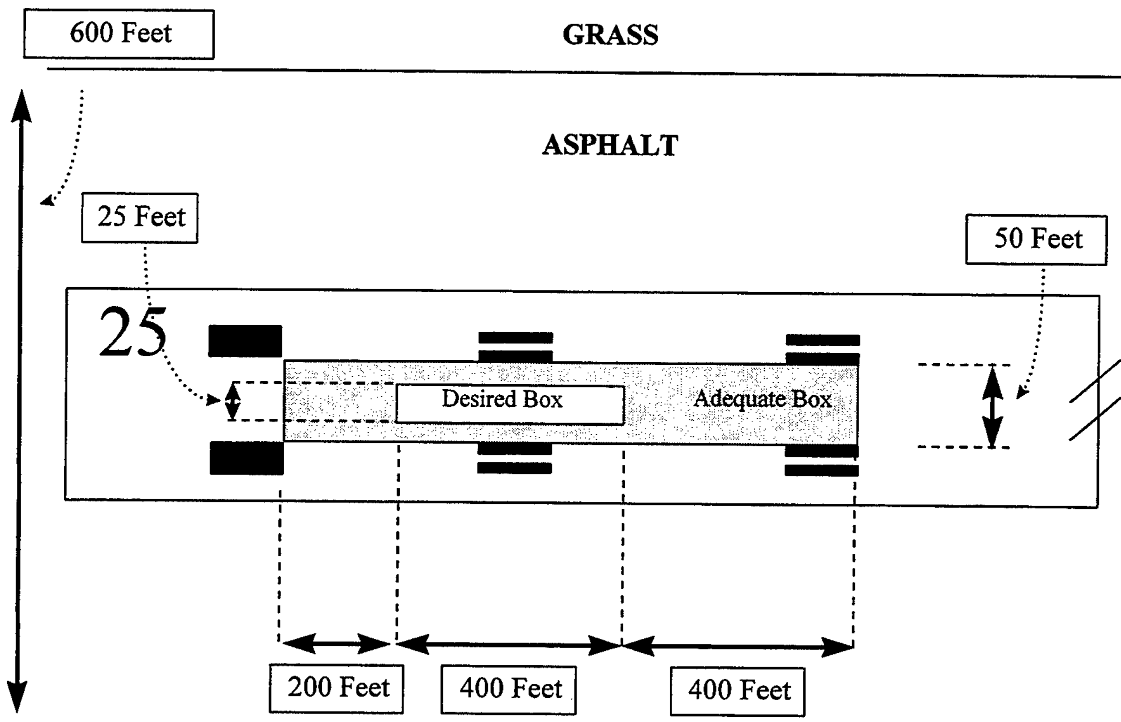

Figure 1 Runway Marking for Offset Landing Box

RESULTS AND ANALYSES

During the HAVE GRIP flight test program, the offset landing task was insufficient to consistently uncover deficiencies in the handling qualities of the aircraft configuration flown. Despite elevator rate limits as low as 5 degrees/second, the pilots were able to routinely achieve desired task performance without significant workload. Following through the Cooper-Harper (CH) rating scale decision tree (Appendix D), these combinations of task performance and pilot workload resulted in Level 1 and 2 handling qualities (CH ratings lower than 6). However, these ratings did not truly reflect the pilots' perceptions of the handling qualities of the configuration. The pilots commented that the handling qualities were worse than the CH ratings indicated. They realized that the configuration had severely limited elevator control and it would have been difficult to recover from steep glideslopes. In the conditions flown, the pilots were able to compensate for the lack of elevator control by making many small corrections long before any big errors in glideslope developed. Because of this, large longitudinal corrections were not usually required. With a more demanding task, or in more turbulent conditions, pilots would likely need to make large or rapid longitudinal corrections and the deficiencies of this configuration would be more evident.

Phase 1:

During this phase, the aircraft configuration (with the nominal stick) was flown with decreasing elevator rate limits to investigate the effects of rate limiting on longitudinal PIOs. Rate limiting did not necessarily cause longitudinal PIOs as indicated by PIO ratings of 4 or 5. The PIO and CH ratings (Appendix D) for the three Phase 1 flights are shown in Figures A1 and A2, respectively. Two of the three project pilots commented that the aircraft began to show some degradation in handling qualities with elevator rate limits starting at 20 degrees/second. The last project pilot did not notice any degradation until the elevator rate limit was 5 degrees/second. Typical comments from these pilots were that the aircraft felt "sluggish" and

there was a noticeable "time delay" in aircraft response. Time histories of the elevator command and elevator position with a 20-degree/second rate limit are shown in Figures A3 and A4. As the rate limits were decreased even further, pilots commented that the aircraft responsiveness seemed to decrease and the apparent time delay between stick input and aircraft response became significant. One pilot gave a PIO rating of 5 with a 10-degree/second elevator rate limit. The PIO was a low frequency, small amplitude oscillation with a period of approximately 4 seconds. The other two pilots had PIO ratings ranging from 2 to 4 with a 5-degree/second elevator rate limit. Based on these results, 7.5 degrees/second was chosen as the elevator rate limits for the stick investigation (Phase 2). Elevator rate limits of 5, 10, and 15 degrees/second were chosen for the investigation of stick dynamics and rate limits (Phase 3).

During Phase 1, the PIO ratings, CH ratings, and pilot comments were influenced by factors other than changes in rate limits. Some of these factors were the initial and final setup for the landing task (i.e., the conditions just prior to and just after the offset correction), winds, gusts, and turbulence. As an example, one pilot flew six consecutive offset landings tasks with the same aircraft configuration (including rate limit) and assigned widely varying PIO and CH ratings for that same configuration (Table G2). The rate limit for these tasks was 5 degrees/second. On four of the six offset landing tasks, the pilot assigned PIO ratings of 2 and CH ratings of 3 and 4 indicating Levels 1 and 2 handling qualities. On the other two tasks, the pilot assigned PIO ratings of 4 and CH ratings of 8 and 10 indicating Level 3 and uncontrollable handling qualities. In other words, the perceived handling qualities of a particular configuration varied greatly from one landing task to another due to factors other than the rate limit.

A summary of the pilot comments and observations from Phase 1 is listed below. A complete listing of the pilot comments can be found in Appendix G.

1. Any oscillations observed were low frequency and low amplitude. Pilot estimated the period of the oscillations to be approximately 4 seconds. One pilot commented that although he felt small oscillations in the stick, he could not feel or see any oscillation in the aircraft motion.

2. The project pilots tended to compensate for the low elevator rate limits by flying the aircraft more open loop.

3. Some oscillations were described as glideslope or vertical velocity oscillations.

4. Any oscillations that did develop tended to develop near the end of the task. Because of this, there was not enough time before touchdown to determine if the oscillations were divergent or not.

Phase 2:

During this phase, the spring constant and natural frequency of the stick were varied independently with a single elevator rate limit determined in Phase 1 in order to identify the two stick configurations to be used in Phase 3.

Spring Constant Variation.

The PIO ratings and CH ratings for the three pilots with 7.5-degree/second elevator rate limits and stick spring constant multipliers (K_s) ranging from 0.6 to 2.2 times the nominal are shown in Figures B1 and B2. There was no definitive trend relating PIO or CH ratings to the stick spring constant. Different pilots liked different stick configurations. Qualitatively, pilots tended to describe the stiff stick (K_s>1 [increased stic force gradient]) as heavy and the aircraft as sluggish and slow to respond. The stick configuration with a spring constant of K_s< 1 was described as light or loose. As in Phase 1, oscillations were of low frequency and small amplitude. Two of the three pilots commented that the stiff stick was worse in terms of task performance and controllability. The stiff sticks made the oscillations more pronounced, while the loose sticks seemed to make the oscillations harder to detect. One pilot felt that he had less control with the stiff stick. The other pilot commented that with the stiff stick, it was easier to maintain desired landing conditions. However, if a gust of wind or pilot distraction resulted in the aircraft being off conditions, then it was harder to correct to the proper glideslope with the stiff stick. For these two pilots, workload definitely increased with the stiff stick. The third pilot felt that with the stiff stick, he was less likely to put in large control inputs and thus less likely to be on the rate limit. For really stiff sticks (K_s>1.8), delays became more evident. Again, with

the stiff stick, this pilot was less willing to put in large control inputs making the aircraft appear more sluggish. Since the pilots preferred different stick configurations, none of which provided significant handling qualities improvements, a spring constant (K_s = 1.4) was chosen for Phase 3 testing to provide a reasonable stick force gradient (i.e., one that might actually be used in an aircraft).

Natural Frequency Variation.

The PIO ratings and CH ratings for the three pilots with 7.5- and 5-degree/second elevator rate limits and the natural frequency multipliers (K_ω) of the stick ranging from 0.4 to 2.2 times the nominal are shown in Figures B3 and B4. There was no definitive trend relating PIO or CH ratings and the natural frequency of the stick. Different pilots liked different stick configurations. All three project pilots commented that sticks with higher natural frequencies were more responsive and sensitive. However, this increase in responsiveness led to very little differences in PIO susceptibility or ability to perform CH task. At K_ω = 1.8, one pilot commented that the stick was too sensitive and felt "jerky." Pilots tended to compensate for the sensitive stick by "backing out of the loop." The project pilots tended to describe the lower frequency sticks (K_ω<1) as heavy with some time delay. In addition, these stick configurations seemed to "float" or "bounce" due to the higher stick inertia needed to reduce the natural frequency. One pilot thought that the stick configuration with a slightly higher natural frequency (K_ω= 1.4) had slightly better handling qualities than the nominal. The second pilot thought the higher frequency stick had marginally worse handling qualities and felt the lower frequency stick had better handling qualities. The third pilot saw little difference with varying stick natural frequencies. Since the pilots preferred different stick configurations, none of which provided significant handling qualities improvements, a natural frequency (K_ω = 1.4) was chosen for Phase 3 testing to provide a reasonable change from the nominal.

During Phase 2, the team discovered that environmental conditions played a large role in the effect of elevator rate limits on PIO and CH ratings. Based on Phase 1 results, the elevator rate limit chosen for the Phase 2 investigation was 7.5 degrees/second. This rate limit was based on flights flown primarily during the mid-morning with low turbulence. During Phase 2, early morning results showed that the 7.5-degree/second rate limit did not produce any oscillations. Because of this, the last two flights in this phase were flown with a 5-degree/second rate limit. For the remainder of the test, it became evident that the gust and turbulence levels greatly influenced the development of PIOs. The pilots commented that gusts and turbulence had a greater effect on the PIO and CH ratings than the variations in the natural frequencies of the stick. In addition, the differences between stick configurations were not significant enough to be reflected on the PIO or CH ratings.

Phase 3:

In Phase 3, the four elevator rate limits determined in Phase 1 were flown with the three stick configurations determined in Phase 2 to investigate the effects of elevator rate limiting and stick dynamics on longitudinal PIO. The elevator rate limits used were 5, 10, 15, and 200 degrees/second. The stick dynamics used were the nominal stick, a stick with 40 percent higher spring constant, and a stick with 40 percent higher natural frequency. The order of the different elevator rates and stick configurations was blind to the pilots. Table F1 details the configurations flown.

Figures C1 to C8 represent the PIO and CH ratings for the different rate limits and stick configurations. Pilot comments for Phase 3 are given in Appendix G. This phase confirmed the results of the previous phases.

Changing the spring constant or natural frequency of the stick had little effect on the PIO or CH ratings for this combination of aircraft dynamics and task. Based on their comments, the pilots could feel the differences between the different sticks, but the differences were not significant, especially in task performance. In addition, the pilots did not agree with regard to which stick configuration reduced the PIO tendency without reducing performance.

The offset landing task was insufficient to consistently uncover handling qualities deficiencies of the aircraft configuration flown. At very low rate limits the problem was the lack of pitch response, not PIO. Any observed oscillations were very low frequency and small in amplitude. These results indicate that the offset landing task flown may not have been optimal to investigate the effects of stick dynamics and elevator rate limits on longitudinal PIOs. A detailed discussion of the choice of offset landing task and configuration for studying PIOs is contained in the Lessons Learned section (Appendix H).

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CONCLUSIONS

The overall objective of the HAVE GRIP flight test program was to investigate the effects of elevator rate limiting and stick dynamics on longitudinal pilot induced oscillations (PIOs). This objective was met, but not with the expected results. In addition, the specific test objectives were met. A range of elevator rate limits and stick dynamics were identified in Phases 1 and 2, and were investigated in Phase 3.

The results of the HAVE GRIP flight test program were specific to this system and led to three major conclusions:

1. The fact that Cooper-Harper (CH) ratings were not consistent with the pilot perceptions of the handling qualities of the aircraft indicated that the offset landing task flown was insufficient to consistently uncover handling qualities deficiencies of the aircraft configuration flown. A detailed discussion of the choice of task and configuration for studying PIOs is contained in the Lessons Learned section (Appendix H).

2. Rate limiting does not necessarily cause PIOs. At very low rate limits, the problem was the lack of pitch response; not PIO. Any observed oscillations were very low frequency and small in amplitude.

3. Changing the spring constant or natural frequency of the stick had little effect on the PIO or CH ratings for this combination of aircraft dynamics and task. For this flight test program, the PIO ratings, CH ratings, and pilot comments were influenced more by the environmental conditions and differences between approach setups than variations in the stick configurations.

These conclusions are specific to this system and may not apply to all aircraft, especially aircraft where PIO tendencies are driven by much higher rate limits.

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APPENDIX A
PHASE 1 DATA PLOTS

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A/C: Learjet 25
S/N: N102VS
Dates: 30 Sep - 2 Oct 96
Source: Flight test

Weight: 10,400 - 11,500 lb
Configuration: 20 deg flaps
Gear down

Stick Spring Gain: $K_s = 1$
Stick Frequency Gain: $K_w = 1$

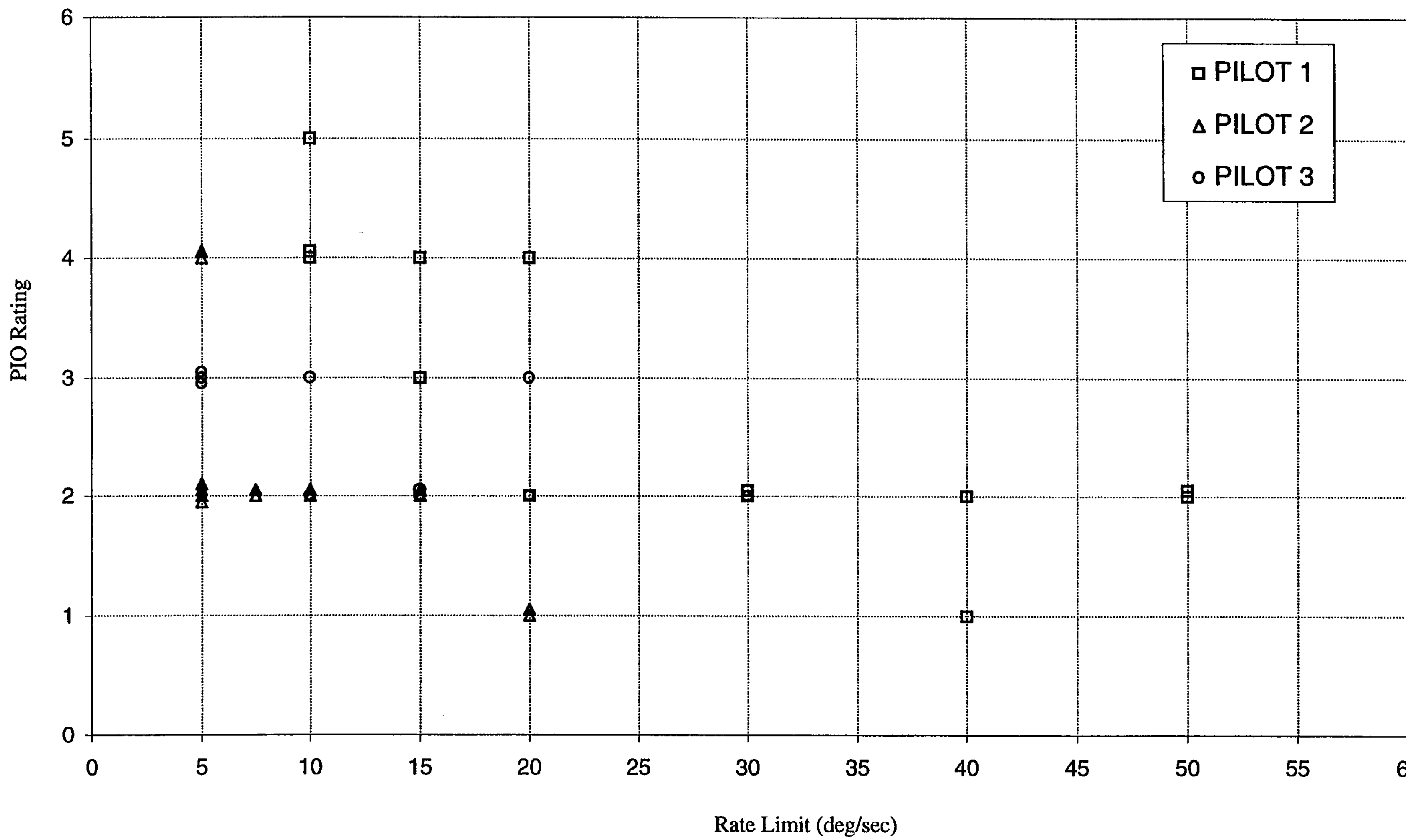

Figure A1 Phase 1 PIO Ratings

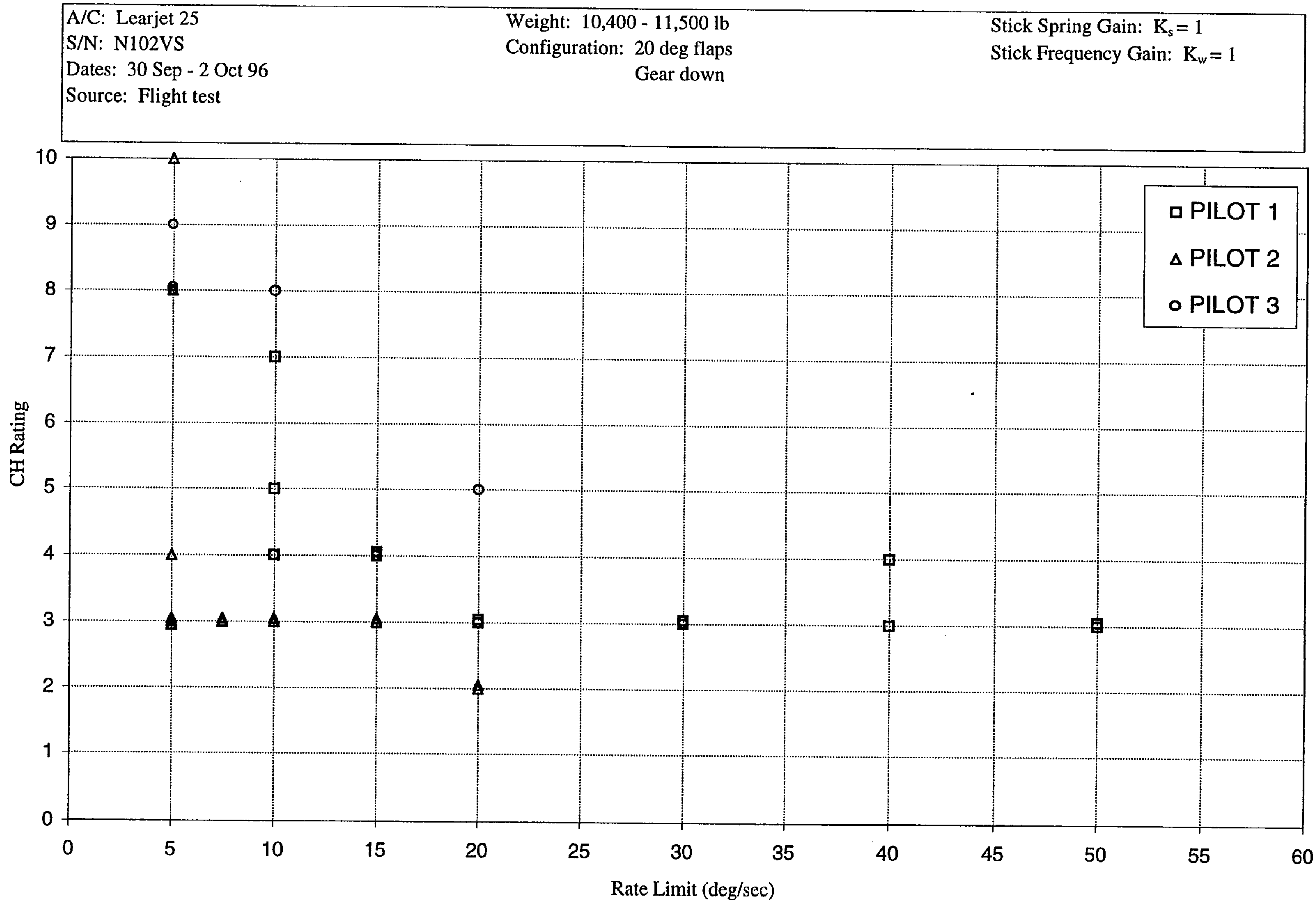

Figure A2 Phase 1 Cooper-Harper Ratings

A/C: Learjet 25	Weight: 10,400 - 11, 500 lb	Stick Spring Gain: $K_s = 1$
S/N: N102VS	Configuration: 20 deg Flaps	Stick Frequency Gain: $K_\omega = 1$
Date: 30 Sept 96	Gear Down	Rate Limit: 20 deg/sec
Flight Number: 6		

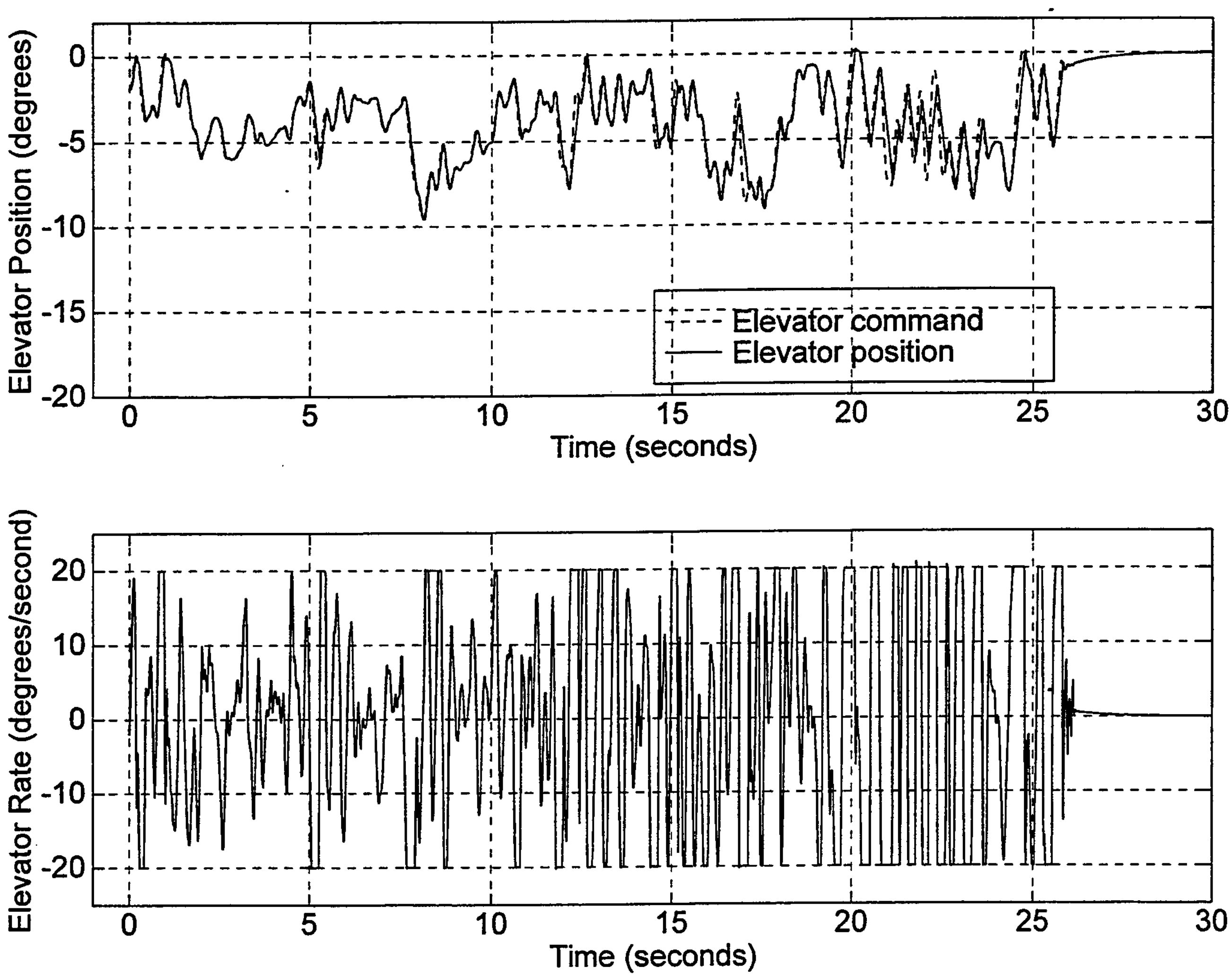

Figure A3 Phase 1 Sample Data Trace, Flight 6

A/C: Learjet 25	Weight: 10,400 - 11, 500 lb	Stick Spring Gain: $K_s = 1$
S/N: N102VS	Configuration: 20 deg Flaps	Stick Frequency Gain: $K_\omega = 1$
Date: 1 Oct 96	Gear Down	Rate Limit: 20 deg/sec
Flight Number: 3		

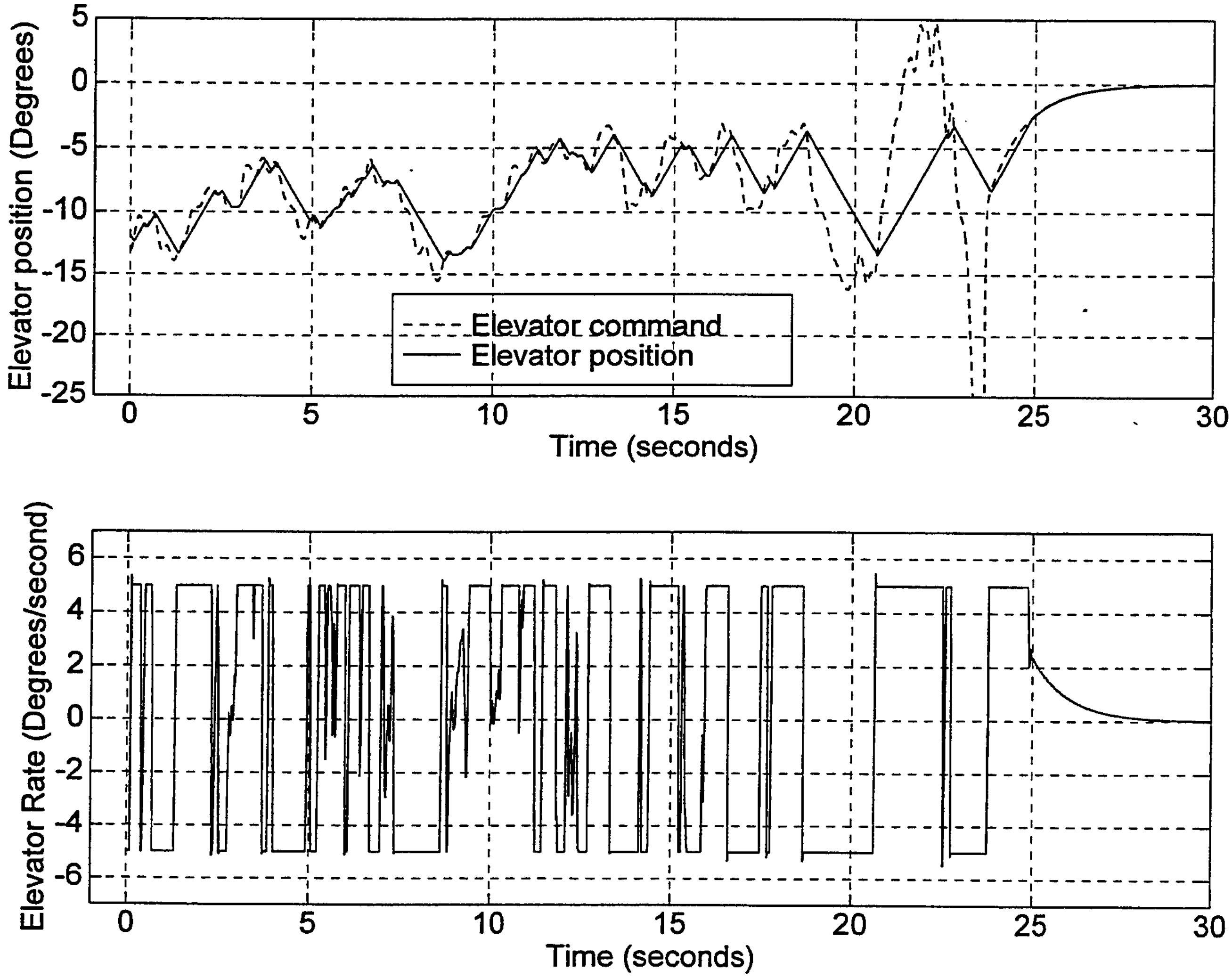

Figure A4 Phase 1 Sample Data Trace, Flight 3

APPENDIX B
PHASE 2 DATA PLOTS

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A/C: Learjet 25 | Weight: 10,400 - 11,500 lb | Natural Frequency Gain: $K_w = 1$
S/N: N102VS | Configuration: 20 deg flaps | Rate Limit: 7.5 deg/sec
Dates: 3 - 9 Oct 96 | Gear down
Source: Flight test

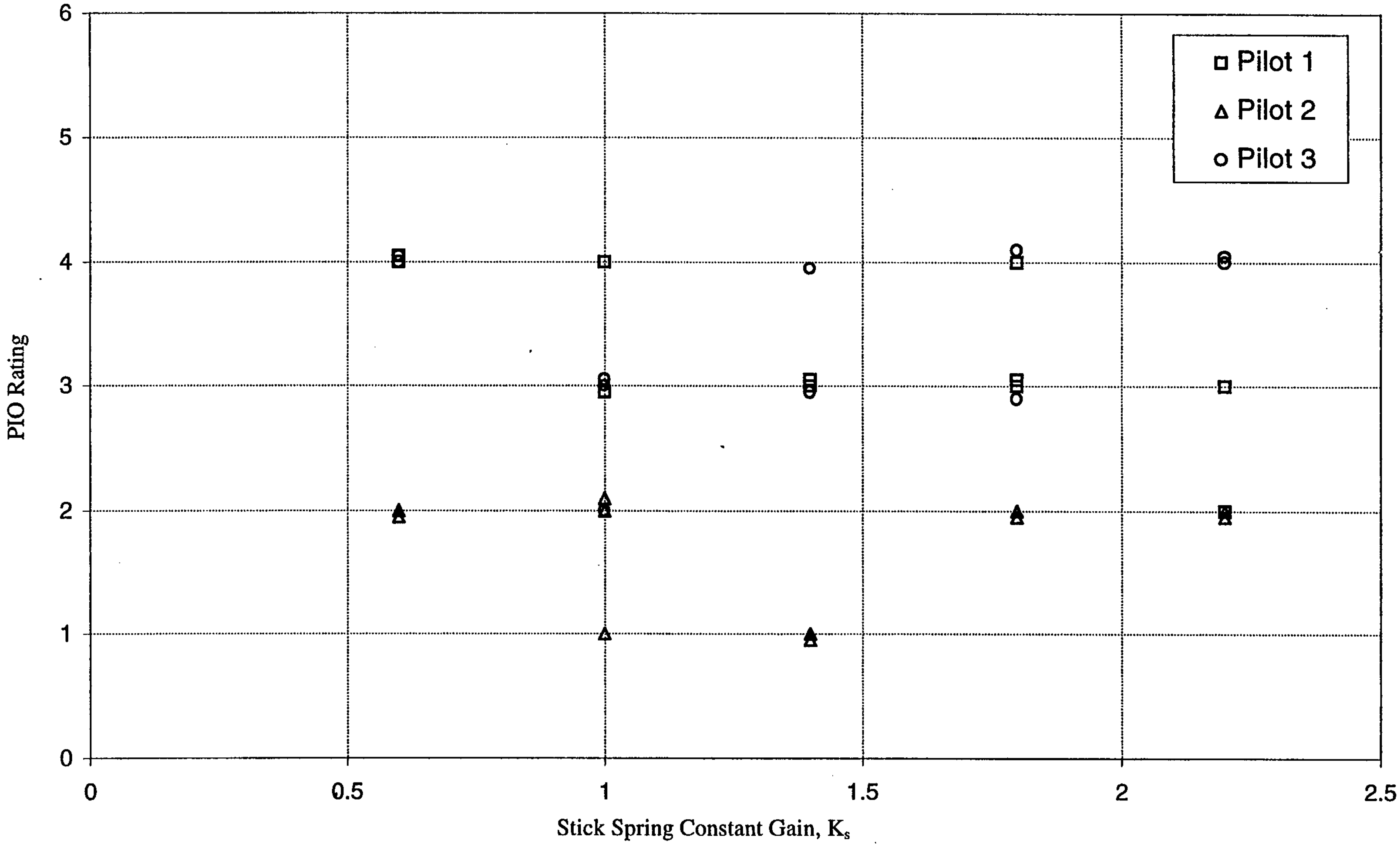

Figure B1 Phase 2 PIO Ratings for Varying Stick Spring Constant

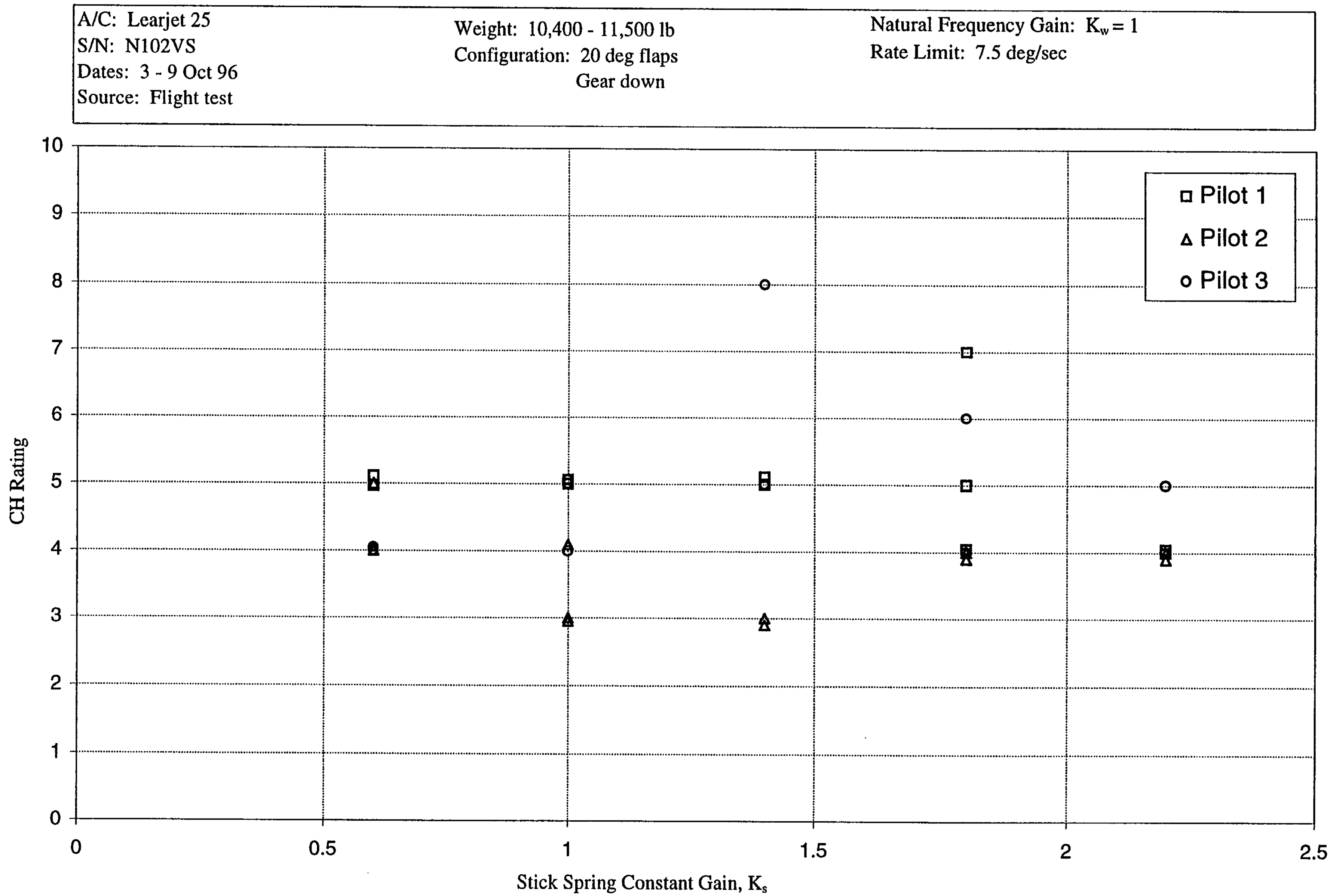

Figure B2 Phase 2 Cooper-Harper Ratings for Varying Stick Spring Constant

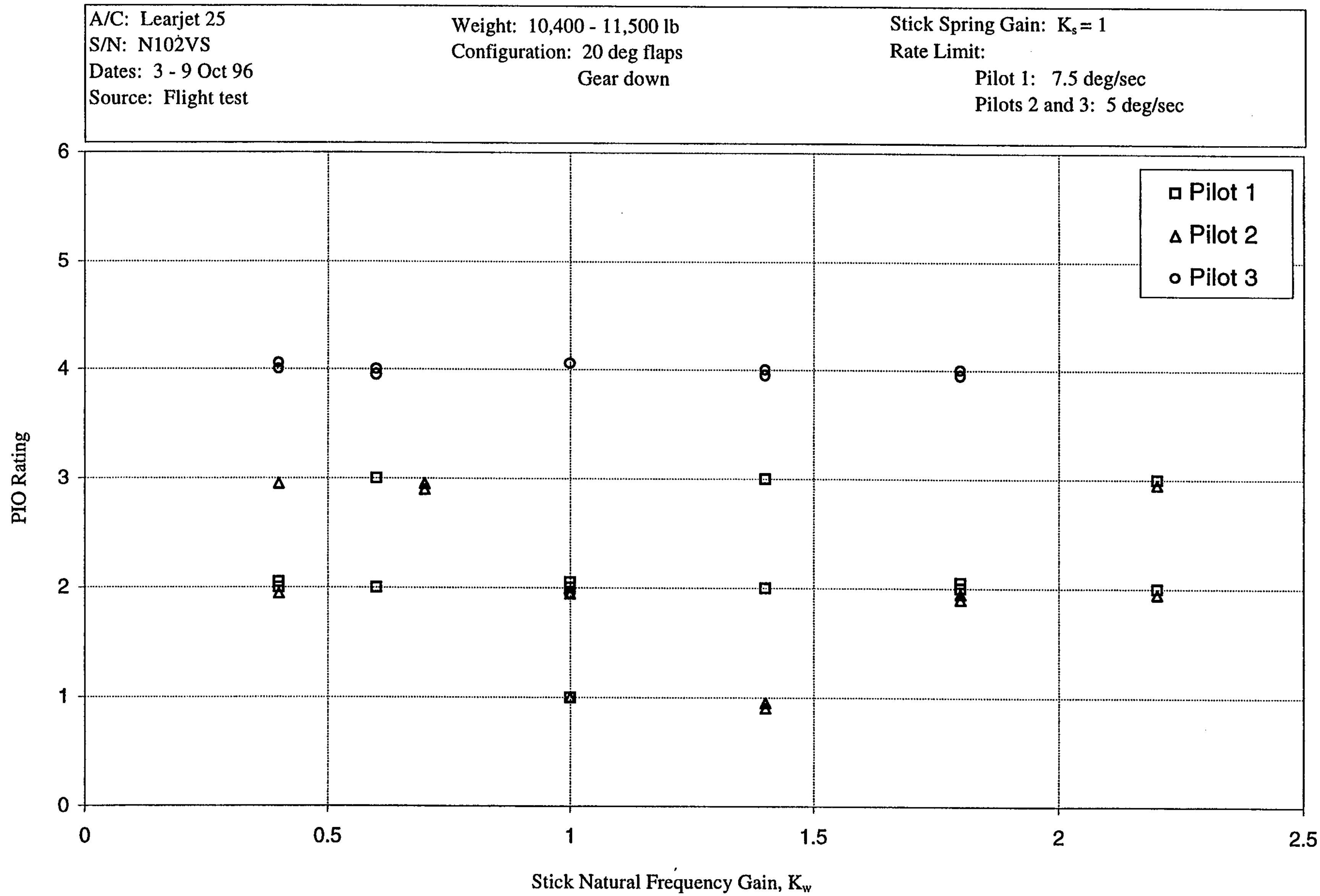

Figure B3 Phase 2 PIO Ratings for Varying Stick Frequency

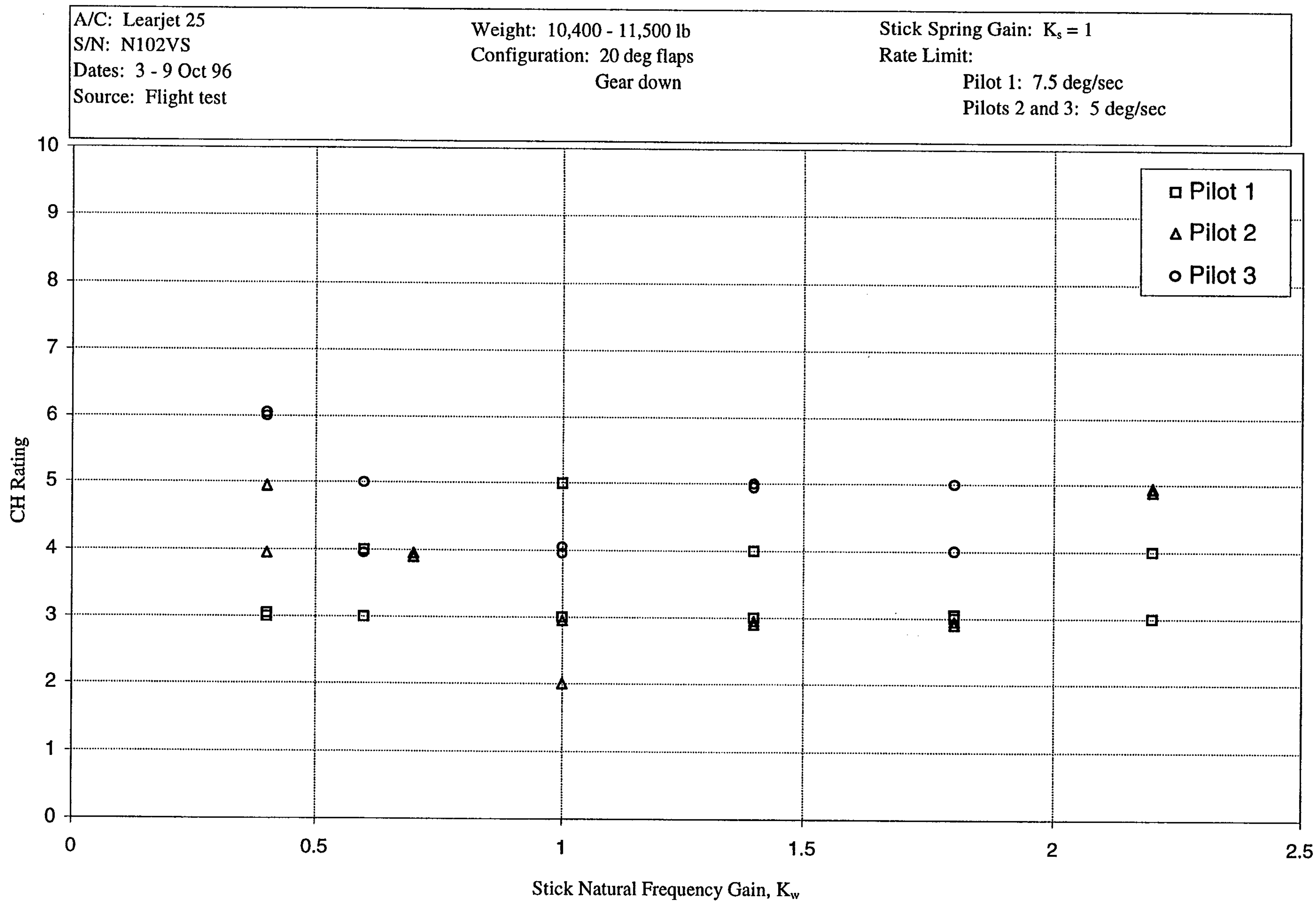

Figure B4 Phase 2 Cooper-Harper Ratings for Varying Stick Frequency

APPENDIX C
PHASE 3 DATA PLOTS

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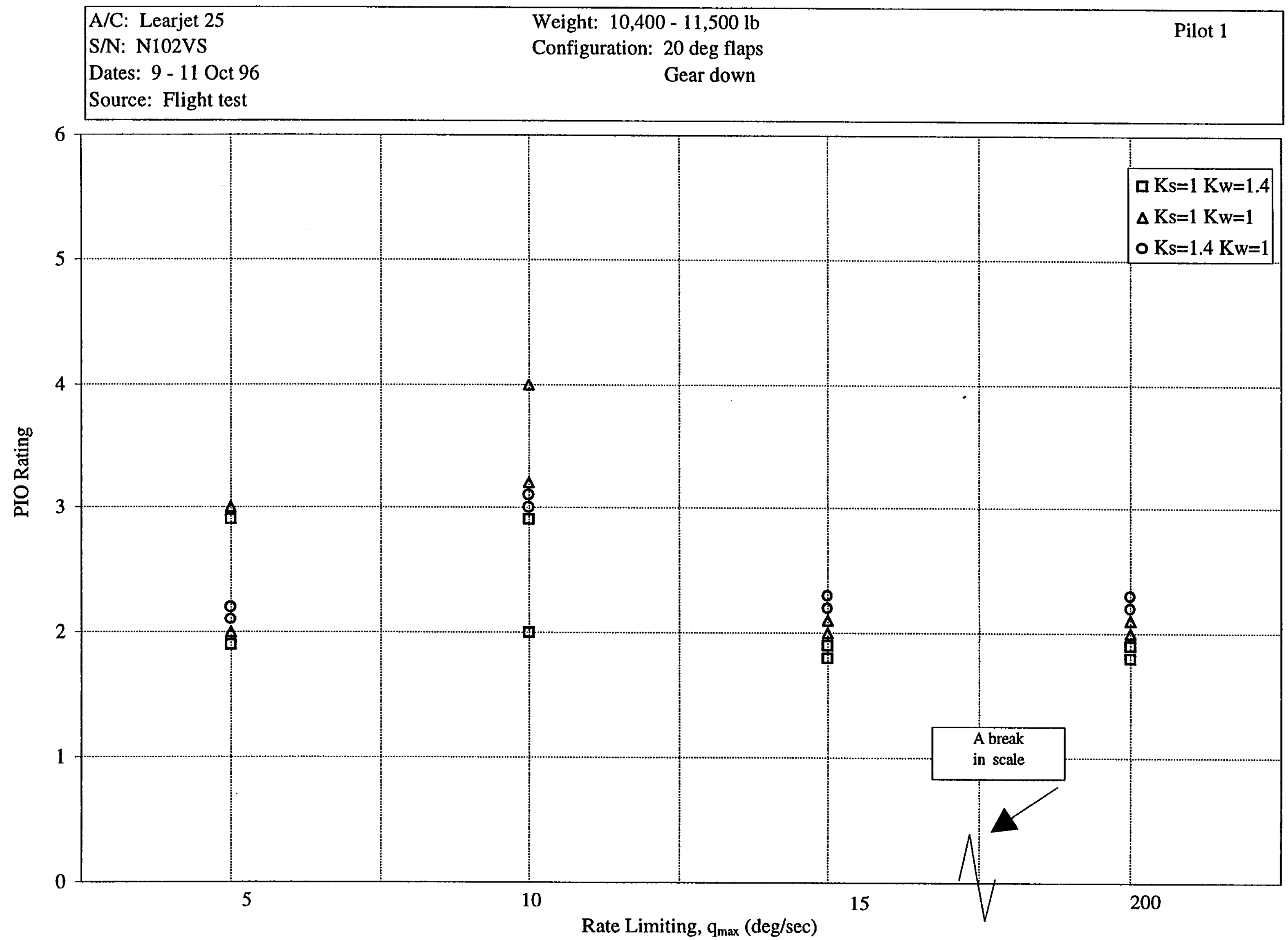

Figure C1 Phase 3 PIO Ratings, Pilot 1

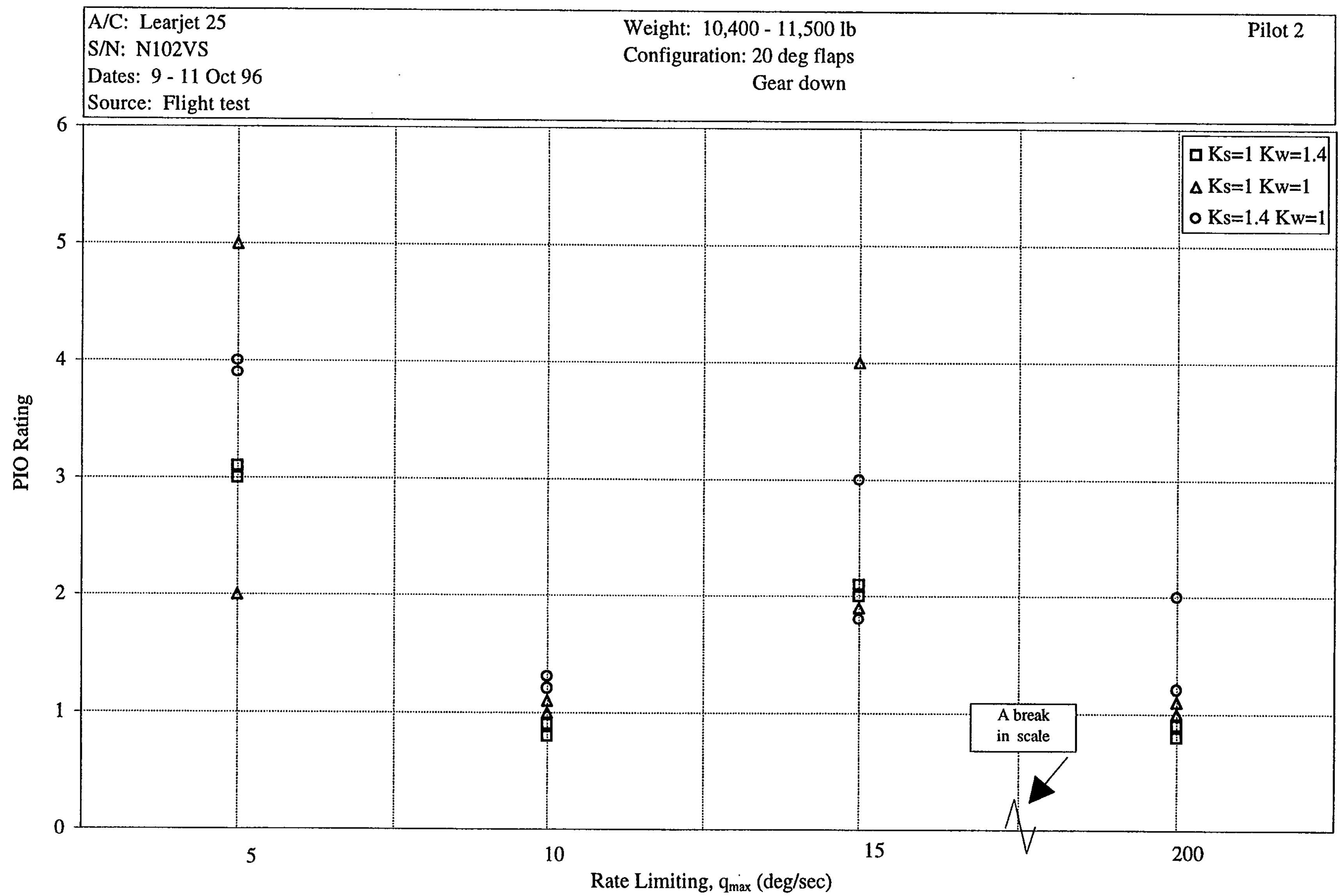

Figure C2 Phase 3 PIO Ratings, Pilot 2

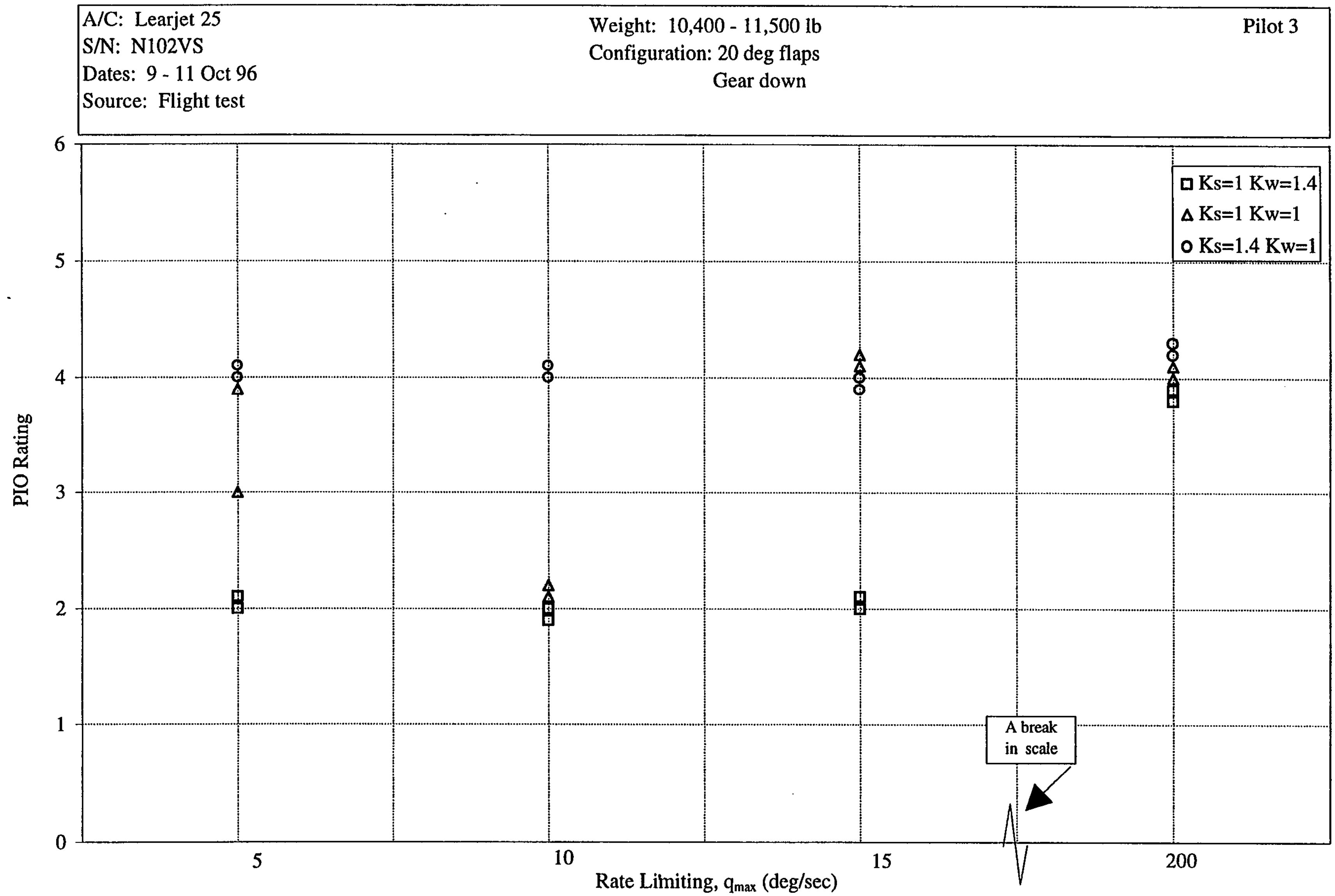

Figure C3 Phase 3 PIO Ratings, Pilot 3

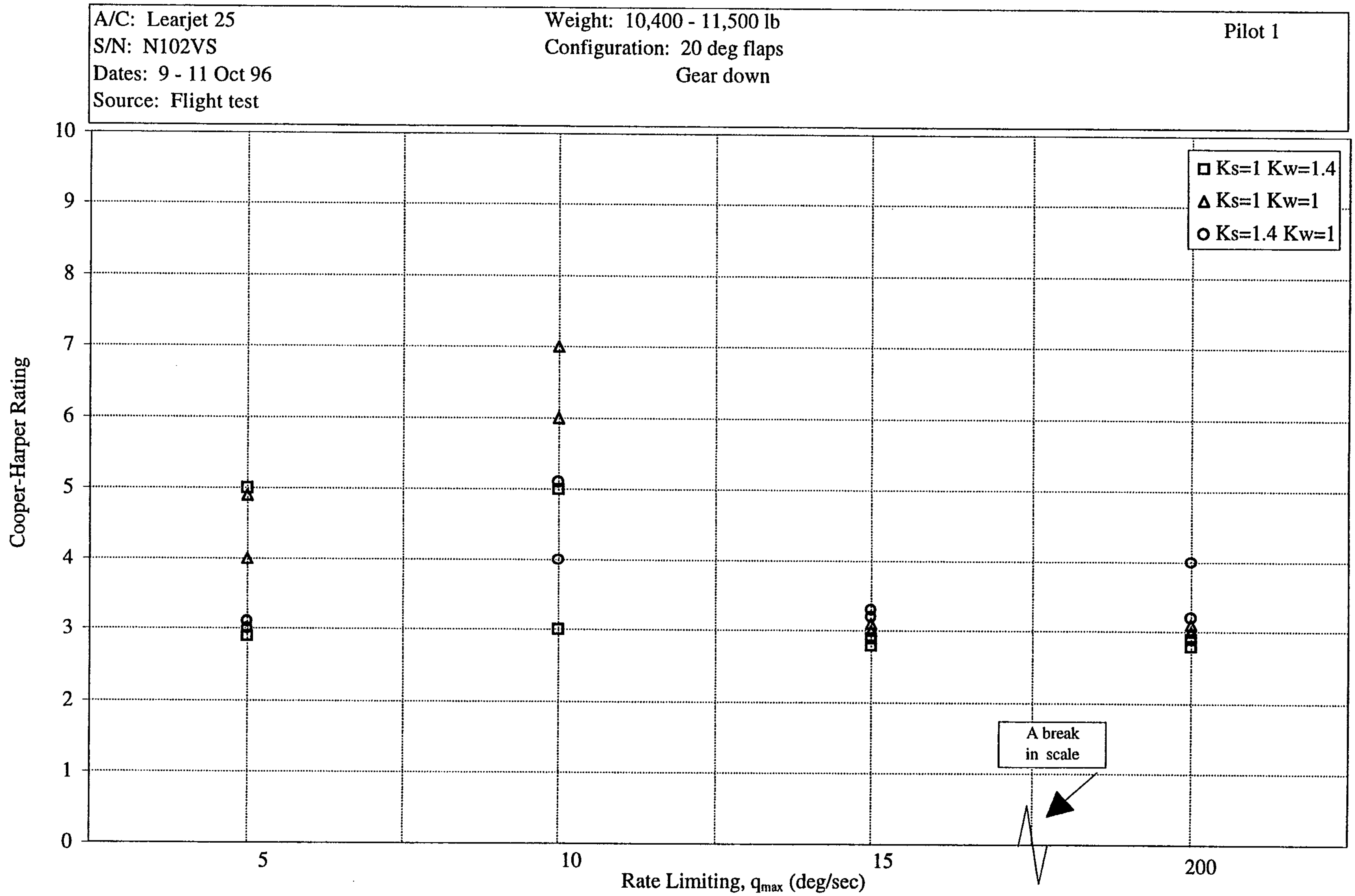

Figure C4 Phase 3 Cooper-Harper Ratings, Pilot 1

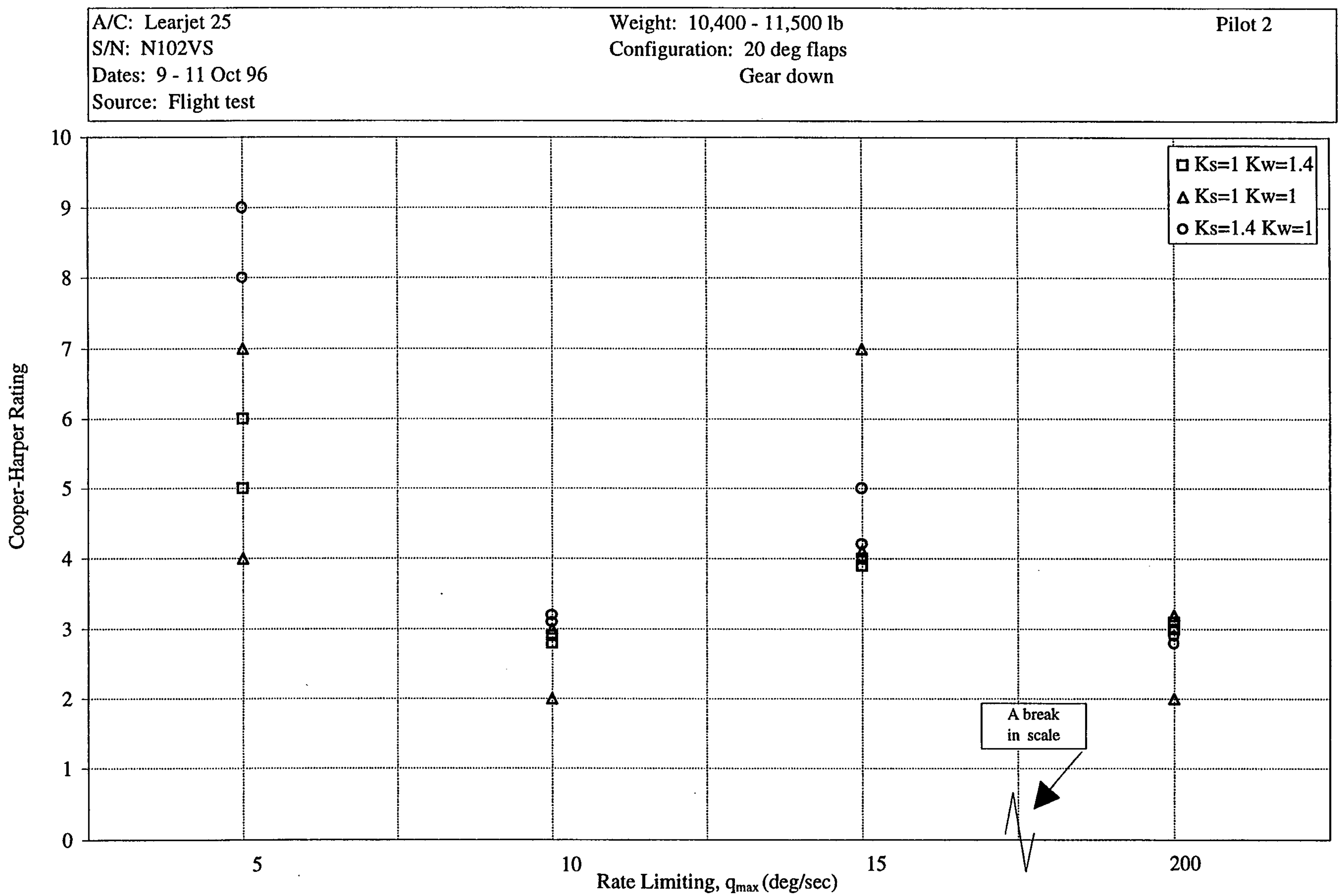

Figure C5 Phase 3 Cooper-Harper Ratings, Pilot 2

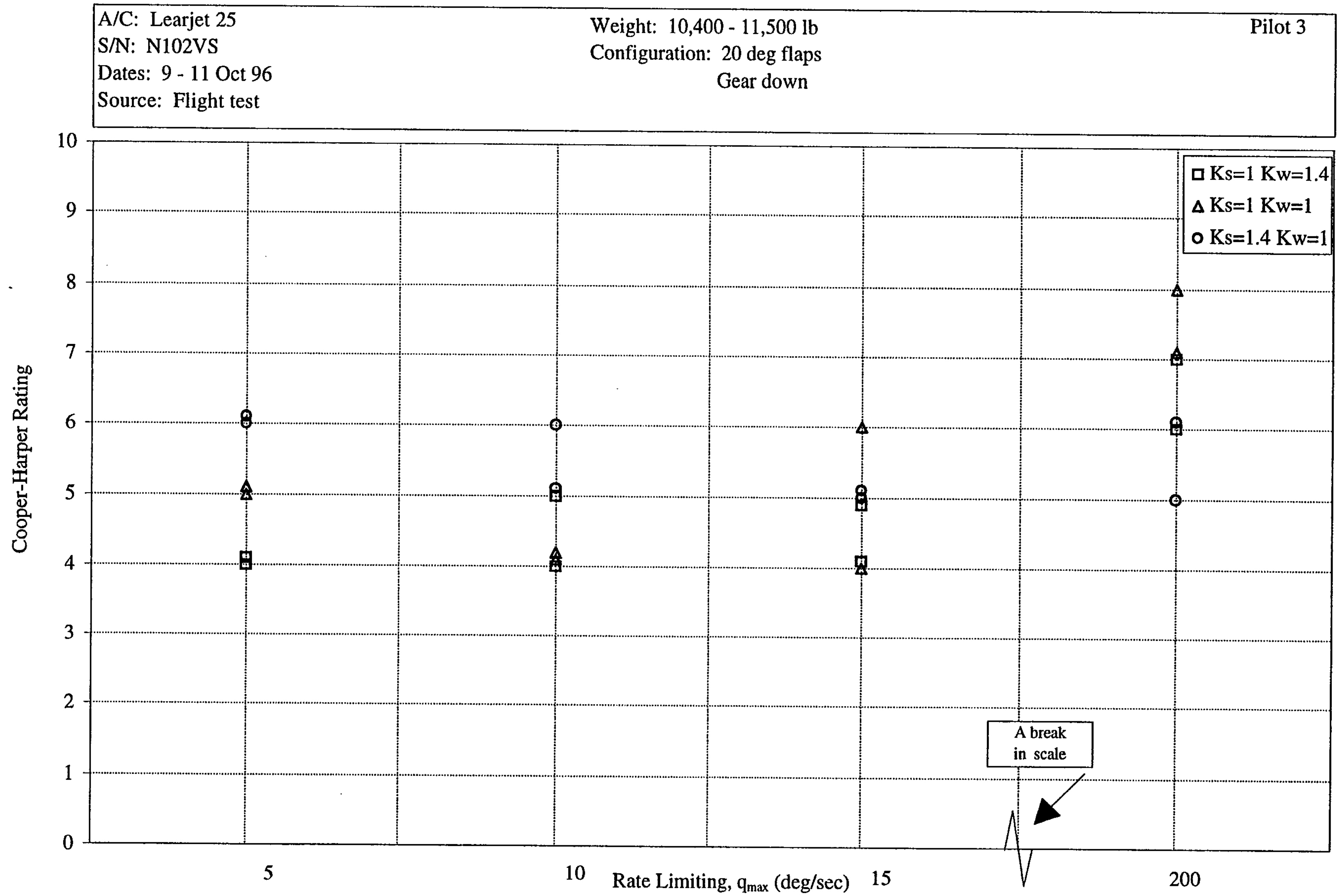

Figure C6 Phase 3 Cooper-Harper Ratings, Pilot 3

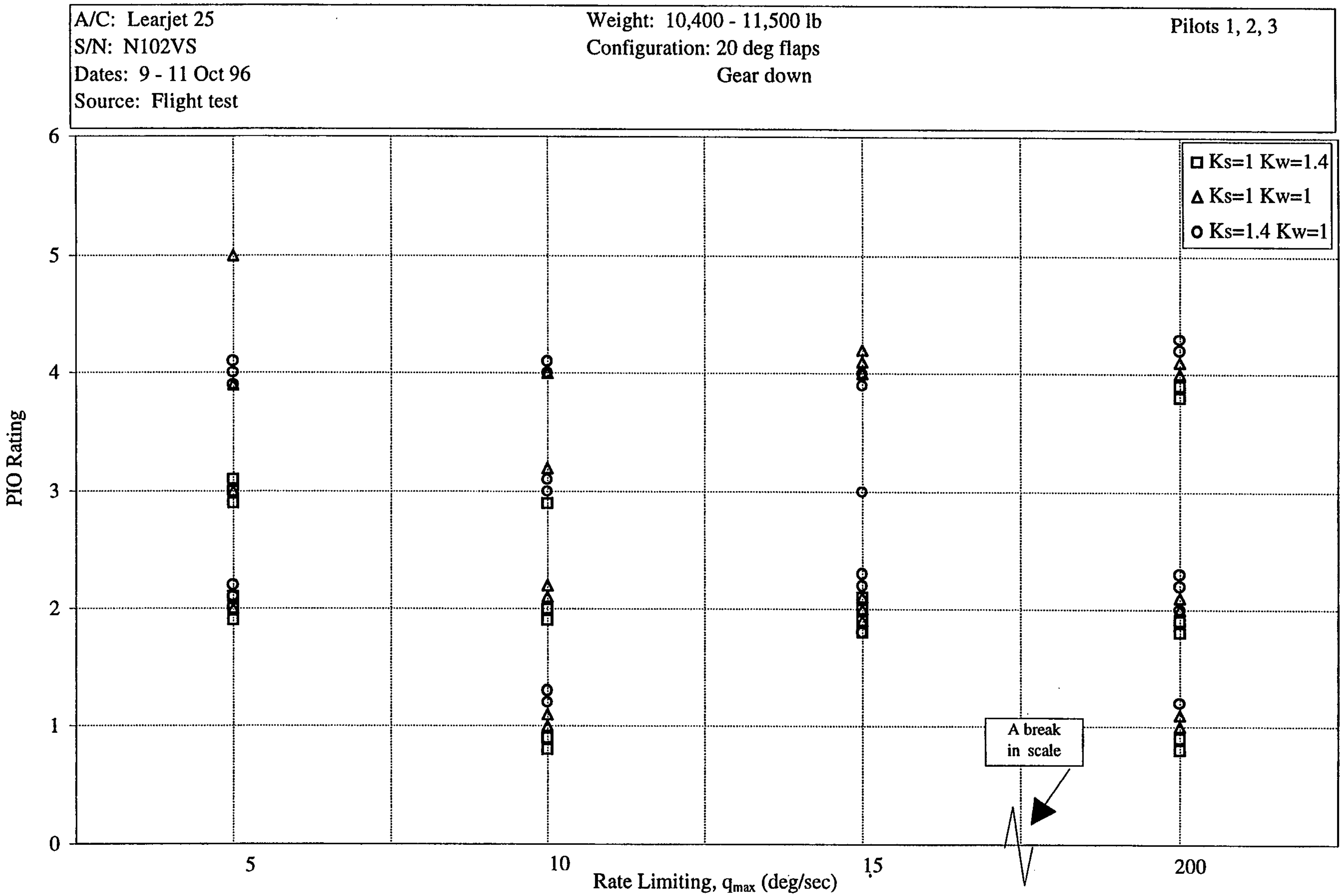

Figure C7 Phase 3 PIO Ratings, All Pilots

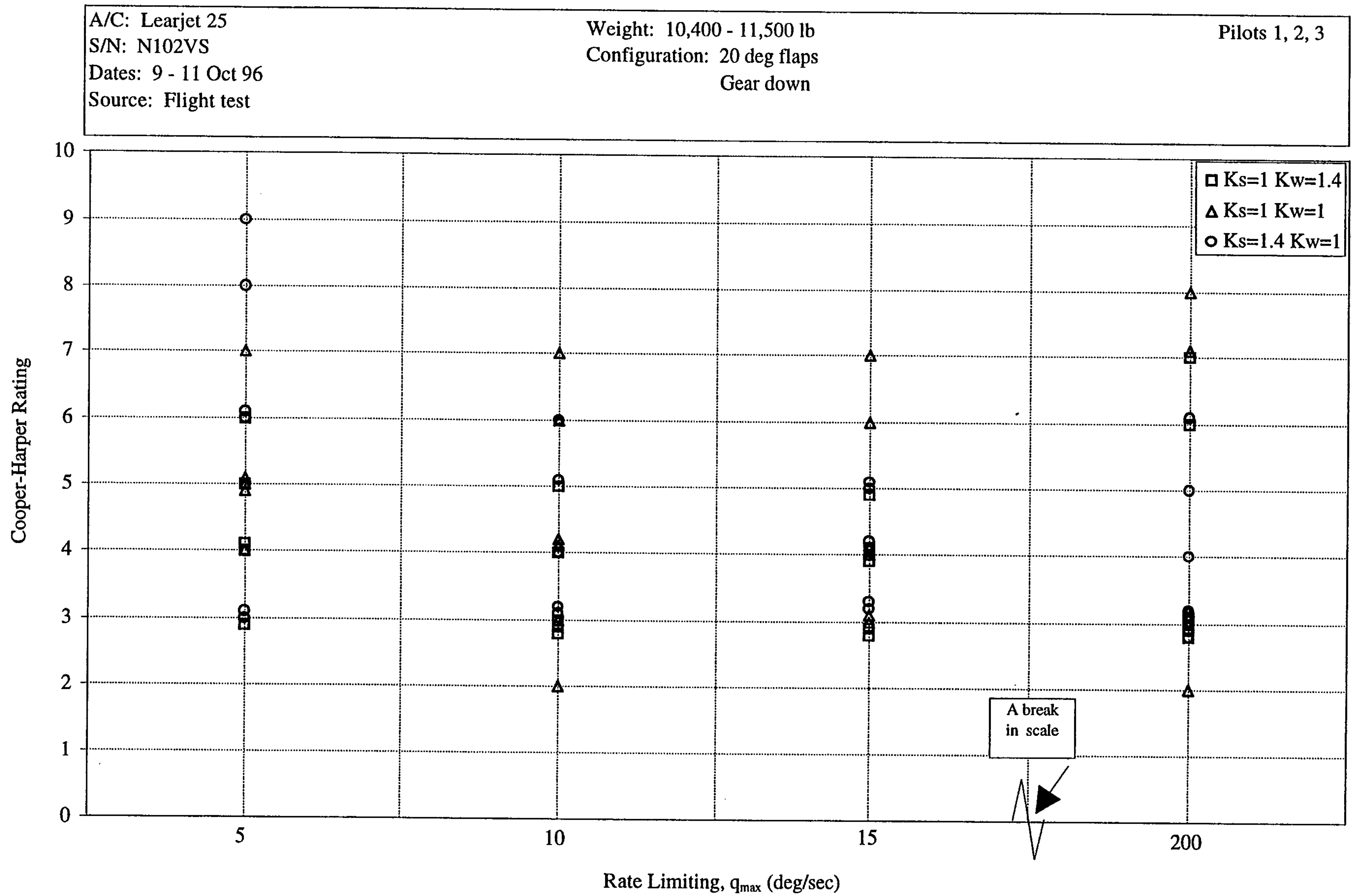

Figure C8 Phase 3 Cooper-Harper Ratings, All Pilots

APPENDIX D
RATING SCALES

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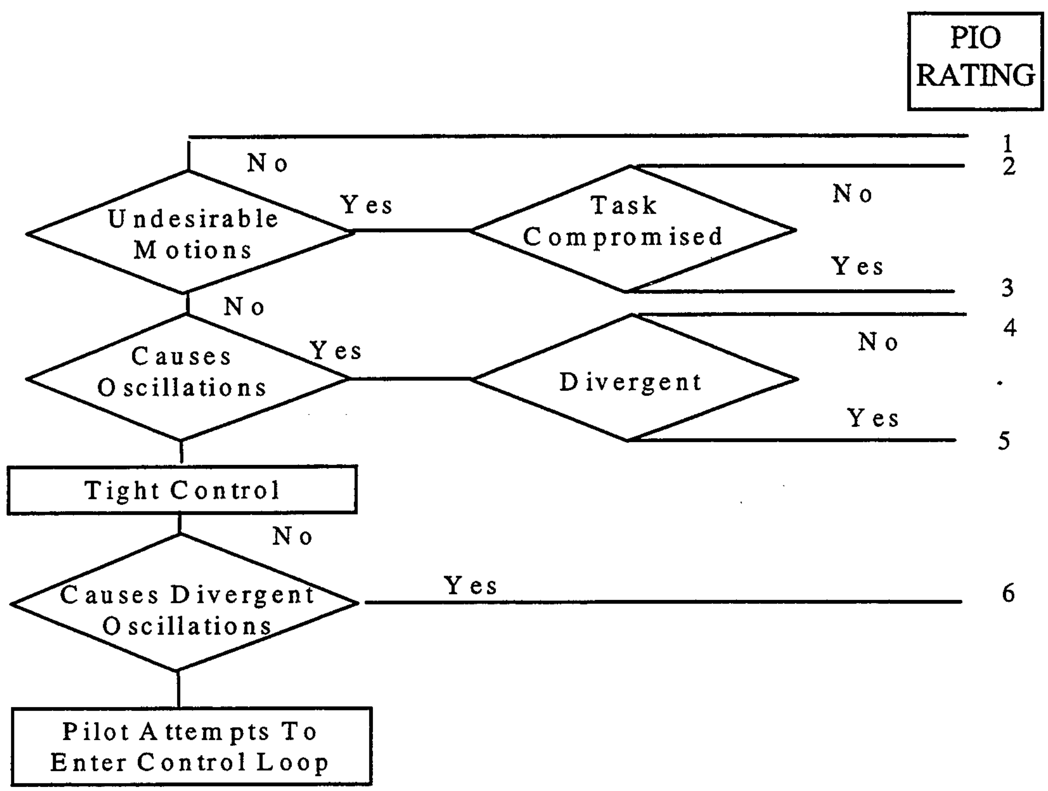
RATING SCALES

PILOT INDUCED OSCILLATION RATING

A pilot induced oscillation (PIO) rating was given for each lateral offset landing task. These, combined with the pilots comments, were the primary data in the HAVE GRIP flight test program. Figure D1 was used by the test director to aid the pilot in determining the appropriate PIO rating (Reference 4). The PIO ratings are structured pilot comments and were used accordingly.



Notes:
1. **PIO 1** – No tendency for pilot to induce undesirable motion.
2. **PIO 2** – Undesirable motion tends to occur when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated by pilot technique.
3. **PIO 3** – Undesirable motions easily induced when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated, but only at sacrifice to task performance or through considerable pilot attention and effort.
4. **PIO 4** – Oscillations tend to develop when pilot initiates abrupt maneuvers or attempts tight control. Pilot must reduce gain or abandon task to recover.
5. **PIO 5** – Divergent oscillations tend to develop when pilot initiates abrupt maneuvers or attempts tight control. Pilot must reduce gain or abandon task to recover.
6. **PIO 6** – Disturbance or normal control may cause divergent oscillation. Pilot must open control loop by releasing or freezing the stick.

Figure D1 PIO Rating Scale Decision Tree

COOPER-HARPER (CH) RATING

A Cooper-Harper (CH) rating was given for each lateral offset landing task as a measure of task performance and pilot workload. The primary purpose of the CH task was to provide a structured, repeatable task which increase the pilots' workload. Figure D2 was used by the Test Director to aid the pilot in determining the appropriate CH rating (Reference 5).

COOPER-HARPER RATING SCALE

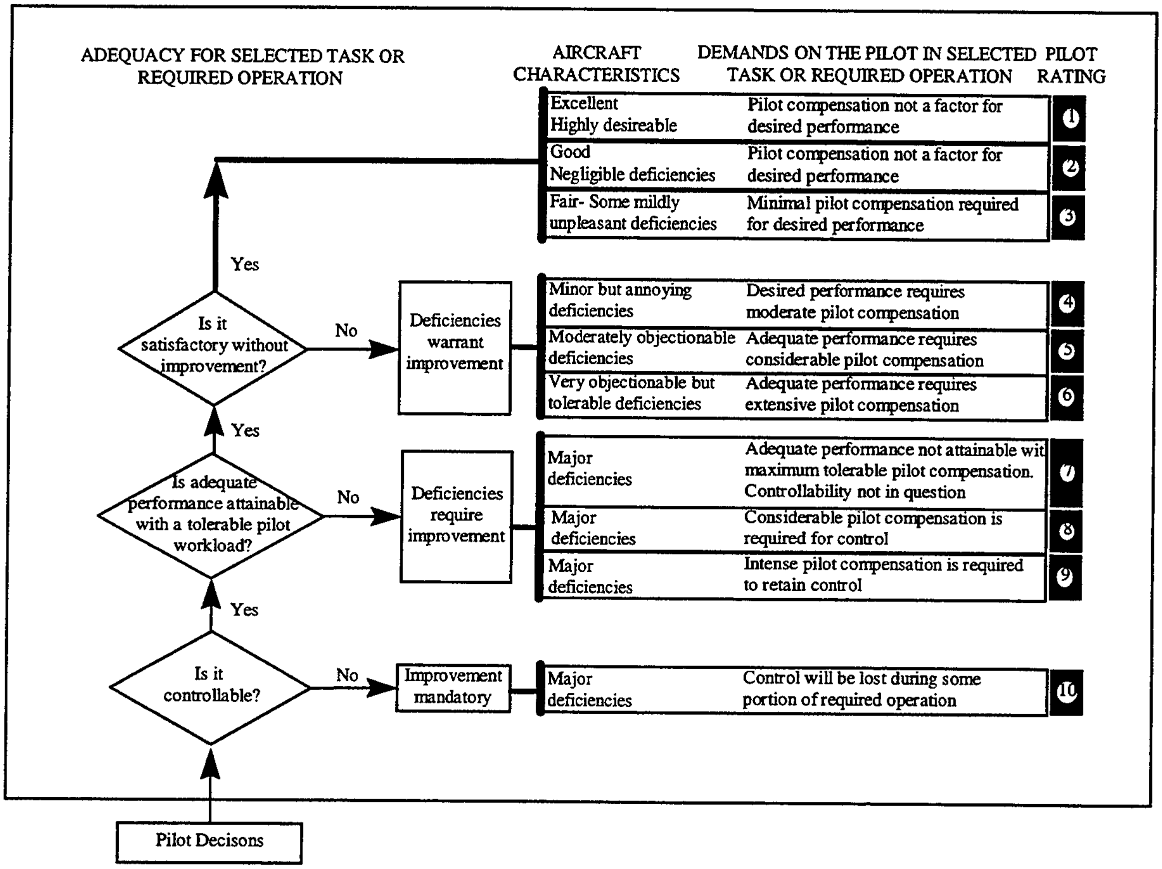


Figure D2 Cooper-Harper Rating Scale

APPENDIX E

DETAILED TEST PROCEDURES

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DETAILED TEST PROCEDURES

The following steps were performed for each test points:

1. At the beginning of each flight the basic Learjet configuration or the nominal stick with a 200-degree/second rate limit was flown as a warmup offset landing maneuver. The basic Learjet configuration was used for the warmup maneuver when the nominal case was tested.

2. Lear II flight control system was configured with the required rate limit/stick dynamic parameters. The Test Director verified the settings were correct.

3. On downwind at pattern altitude, the Variable Stability System was engaged and the test pilot took control of the jet.

4. A visual pattern was flown to Setup for a lateral offset 300 feet to the left of the runway centerline at a 2 nautical mile final. The ILS glideslope aim point was at the beginning of the adequate box. The test pilot flew 300 feet offset and on ILS glideslope to 200 feet above the runway and, at that point, aggressively corrected to the centerline. The pilot used 30 to 45 degrees of bank for the initial corrections and all gross corrections were completed by 50 feet above the runway. The aim was to flare so as to touchdown in the desired box at a touchdown speed 10 knots less than approach speed. The test pilot provided comments for each landing flown, along with pilot induced oscillation and Cooper-Harper ratings against the tasks described below. The task was then be repeated with the same rate limit and stick configuration to collect a second set of comments and ratings. After two landings in a given configuration, the test pilot determined if the landings were representative of the flight control system under test. The Test Director then determined if the test point was complete and whether or not to proceed with the next test point.

5. The next test block will then be performed or the test mission will be called complete.

OFFSET LANDING TASK

Setup:

1. Roll out on a 2-nautical mile final to Setup for a ILS glideslope (600 feet above ground level at 2 nautical miles).

2. Glideslope runway intercept point should be at the beginning of the adequate box.

3. Setup offset 300 feet to the left of the centerline when rolling out on final.

4. Fly at 125 to 135 KIAS (weight dependent) on final.

5. Correct to centerline with an aggressive input at 200 feet above the runway.

6. Plan to flare so as to touchdown inside the desired box.

7. Touchdown at 10 knots less than approach speed.

Table E1
OFFSET LANDING COOPER-HARPER TASKS

Performance Level	Criteria
DESIRED	Soft landing within the desired box (see Figure 1) Touchdown on speed ±5 knots
ADEQUATE	Soft landing within the adequate box (see Figure 1) Touchdown on speed +10/-5 knots

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APPENDIX F
TEST CONFIGURATIONS

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TEST CONFIGURATIONS

The aircraft system model used in the HAVE GRIP flight test program is described in the Figure F1. This figure shows how the Lear II simulates the desired aircraft dynamics and flight control system. For this project, the diagram could be simplified as shown in Figure F2. The components of Figure F2 are discussed in the text following the figures.

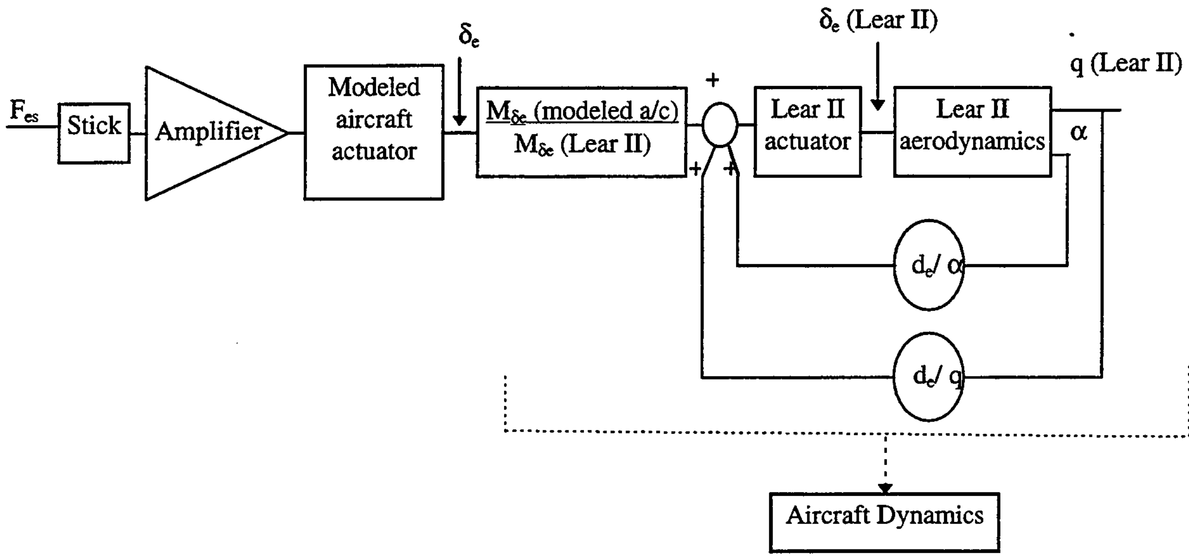

Figure F1 Aircraft Block Diagram

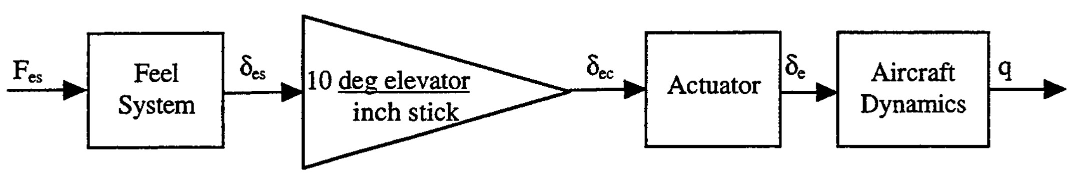

Figure F2 Pilot/Aircraft Systems Block Diagram

FEEL SYSTEM DESCRIPTION

The HAVE GRIP stick dynamics (feel system) were modeled by the following equation:

$$\frac{\delta_{es}}{F_{es}} = \frac{0.125K_S}{[0.6,\ 26K_\omega]} \text{in / lb}$$

The equation is written in shorthand notation where:

$[\zeta,\omega_n] = (s^2 + 2\zeta\omega_n s + \omega_n^2)$ and

$(a) = (s + a)$

The parameters K_S and K_ω were varied to make the different stick configurations. Table F1 defines the rate limiting, K_S and K_ω for each stick configuration flown during the test program. The nominal stick spring constant was 8 pounds/inch. A multiplier, K_s, of 1.4 resulted in spring constant of 11.2 pounds/inch. The nominal stick frequency was 26 radians/second. A multiplier, K_ω of 1.4 resulted in spring frequency of 36.4 radians/second. The stick had a breakout force of 0.75 pound.

Table F1
DESCRIPTION OF HAVE GRIP TEST CONFIGURATIONS

Phase	Pilot	Rate Limit (deg/sec)	Stick Spring Multiplier	Stick Frequency Multiplier
1	1, 2, 3	200	1	1
	1	50, 40, 30, 20, 15, 10	1	1
	2	20, 15, 10, 7.5, 5	1	1
	3	30, 20, 15, 10, 5	1	1
2	1, 2, 3	7.5	0.6, 1, 1.4, 1.8, 2.2	1
	1	7.5	1	0.4, 0.6, 1, 1.4, 1.8, 2.2
	2	5	1	0.4, 0.7, 1, 1.4, 1.8, 2.2
	3	5	1	0.4, 0.6, 1, 1.4, 1.8
3	1, 2, 3	200	1, 1.4	1
	1, 2, 3	200	1	1, 1.4
	1, 2, 3	15	1, 1.4	1
	1, 2, 3	15	1	1, 1.4
	1, 2, 3	10	1, 1.4	1
	1, 2, 3	10	1	1, 1.4
	1, 2, 3	5	1, 1.4	1
	1, 2, 3	5	1	1, 1.4

ACTUATOR

The hydraulic actuator used in the HAVE GRIP simulations are depicted in Figure F3. Included in this model were the rate limits that were varied during the testing.

When not rate limited, the actuator dynamics simplify to:

$$\frac{\delta_e}{\delta_{ec}} = \frac{1}{[0.7, 75]}$$

AIRCRAFT DYNAMICS

The aircraft configuration used for all HAVE GRIP flight tests was Configuration 2-1 from HAVE PIO (Reference 2). The transfer function for this configuration was simulated by the Lear II except for the phugoid mode:

$$\frac{q}{\delta_e} = \frac{3.3685(0.0845)(0.6990)(0)}{[0.15,0.17][0.63,2.41]}$$

On the next page, the Bode plot of the aircraft dynamics (q/δe) is shown (Figure F4). On the following page, a comparison between the model simulation and flight test response to a step input is also shown (Figure F5).

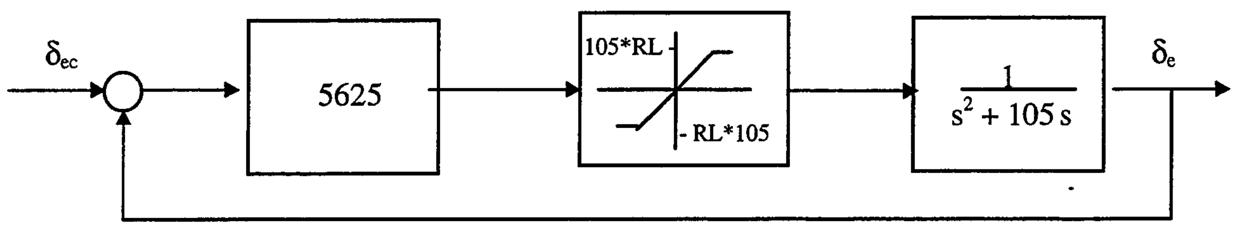

Figure F3 Hydraulic Actuator Block Diagram

Aircraft Model
Calculated Data
Date: 15 November 1996

$$\frac{q}{\delta_e} = \frac{3.3685(0.0845)(0.6990)(0)}{[0.15,0.17][0.63,2.41]}$$

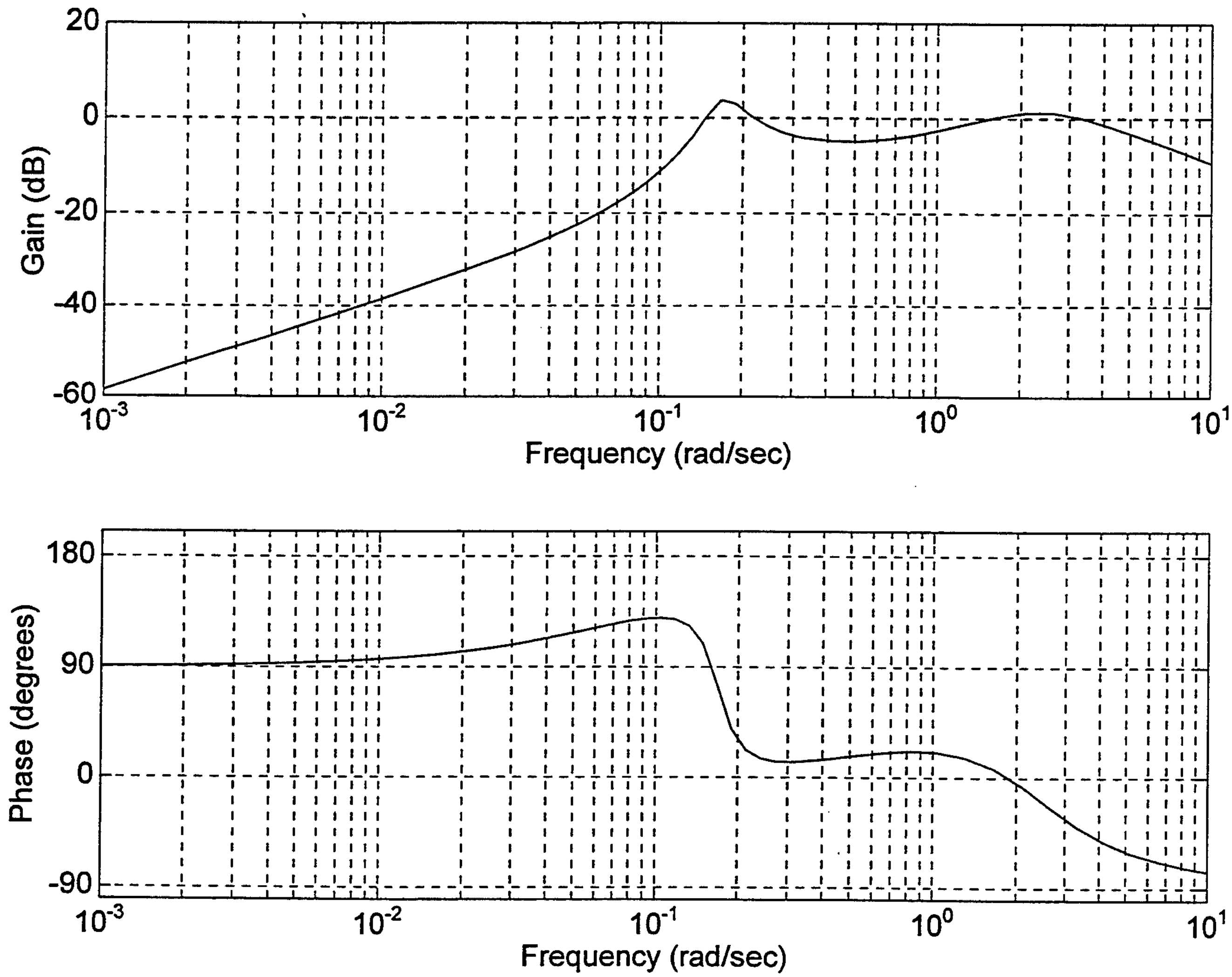

Figure F4 Bode Plot of Aircraft Dynamics

A/C: Learjet 25	Weight: 10,400 - 11, 500 lb	Stick Spring Gain: $K_s = 1$
S/N: N102VS	Configuration: 20 deg Flaps	Stick Frequency Gain: $K_\omega = 1$
Date: 11 Oct 96	Gear Down	Rate Limit: 20 deg/sec
Flight Number: 14		

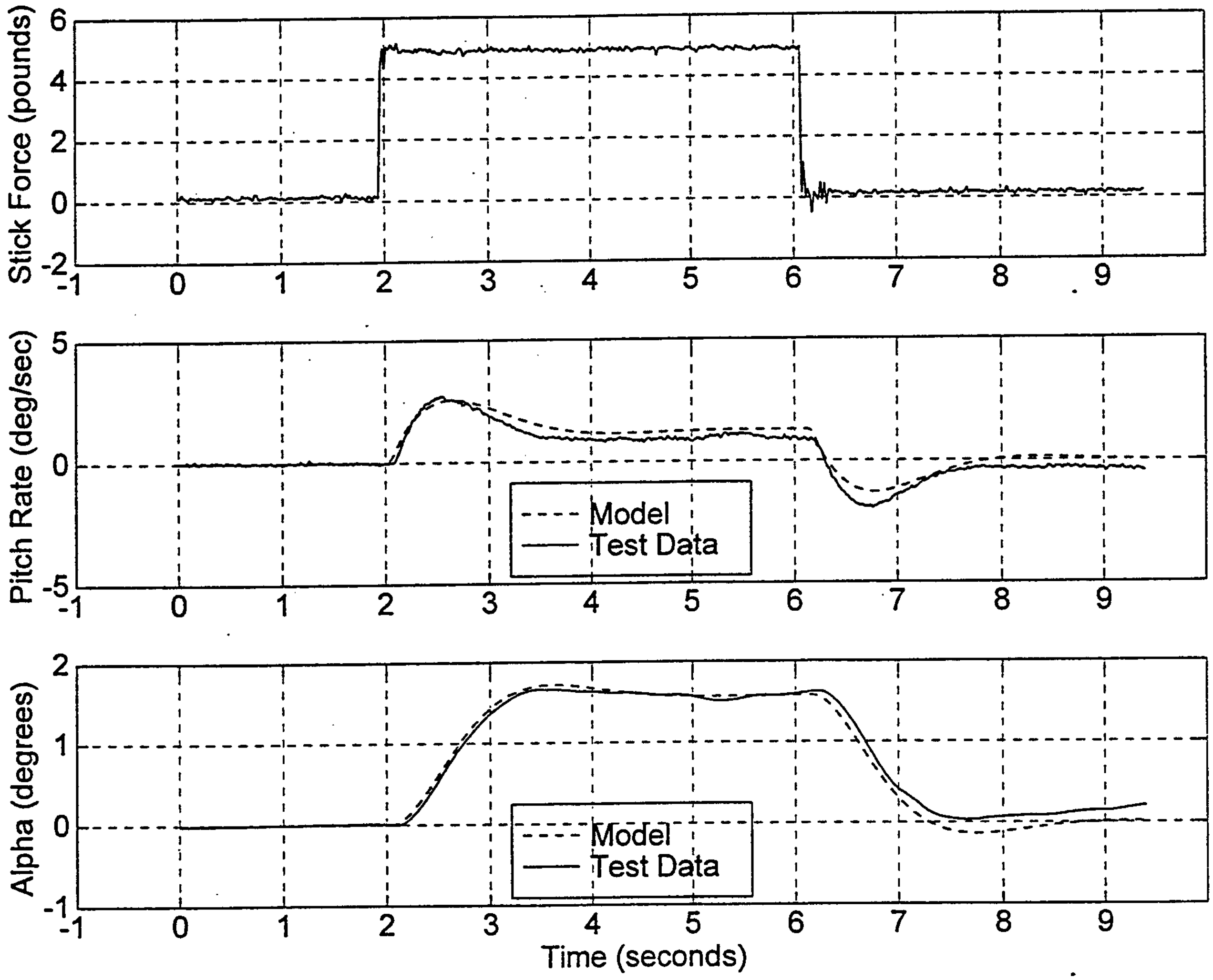

Figure F5 Model Simulation and Aircraft Response to a Step Input

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APPENDIX G
SUMMARIZED COMMENTS FROM EACH FLIGHT

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Table G1
FLIGHT 1, PHASE 1

PILOT: Peters			DATE: 30 Sept 96			FLIGHT No.: 1 / Test Phase: 1
Run No.	K_s, Spring	K_ω, Frequency	Rate Limit (deg/sec)	PIOR	CHR	Comments
1	1	1	Lear Jet	---	---	Warmup Landing.
2	1	1	200	2	4	Sensed small oscillations through stick. Max elevator rate used 55 deg/sec.
3	1	1	200	2	3	Same as run 2.
4	1	1	50	2	3	Max elevator rate used 45 deg/sec.
5	1	1	50	2	3	Borderline PIO rating of 1 or 2. Touched elevator rate = 50 deg/sec once in flare.
6	1	1	40	2	4	Hit rate limit 10 times. Touched 40 deg/sec once.
7	1	1	40	1	3	Hit rate limit only 1 time. Touched 40 deg/sec once.
8	1	1	30	2	3	Hit rate limit 12 times. Touched 30 deg/sec 17 times.
9	1	1	30	2	3	Hit rate limit 5 times. A lot of limit cycle oscillation going on.
10	1	1	20	4	3	Pilot was making a lot of small corrections but didn't effect task. Plane not oscillating. On rate limit 20% of time.
11	1	1	20	2	3	Touched rate limit 5-10 % of time.
12	1	1	15	4	4	Pilot could feel oscillatory motion in aircraft. Felt sluggish, but not bad. On rate limit 5-10% of time.
13	1	1	15	3	4	Less pilot compensation this time (hand wasn't moving as much as previous runs). Light Turbulence. Touched rate limit 30% of time.
14	1	1	10	4	4	Not as responsive as previous rate. Noticeable drop in elevator effectiveness. Touched rate limit 50% of time.
15	1	1	10	5	7	Twice hit rate limit and held there for 1.5 seconds. Touched rate limit 80% of time.
16	1	1	10	4	5	Okay control to flare, but not enough to eliminate sink rate and land smoothly. Touched rate limit 50% of time.

Notes:
1. K_s - stick spring constant multiplier
2. K_ω - stick natural frequency multiplier
3. PIOR - pilot induced oscillation rating
4. CHR - Cooper-Harper rating
5. --- no comments
6. General comments on Flight 1:

   a. RL=200 deg/sec: The next two approaches were flown with RL=200 deg/sec and the elevator rates (derate) were observed during the approaches and landings. On each approach, the derate had one or two spikes of about 55 and 65 deg/sec during the flare, with the rest of the peaks around 30-40 deg/sec. Based on these spikes, the test director decided to use 50 deg/sec as the next test point. **PIOR: 2/2. CHR: 4/3.**

b. RL=50 deg/sec: The two approaches flown at 50 deg/sec showed that the pilot was still improving more based on becoming more familiar with the task than he was being hindered by the rate limiting. No difference was noted by the pilot from the previous (basically unlimited) case. In fact, derate never reached the limit on one of the two approaches. The remaining Phase 1 flights should use the predominant peaks in derate rather than the one or two spikes to determine the initial rate limit. This should allow for more approaches at the lower rate limits. **PIOR: 2/2. CHR: 3/3.**

c. RL=40 deg/sec: Pilot technique was still improving and no degradation in performance was noted. At least two warmup approaches should be flown prior to any actual test points. This should help keep the pilot's learning curve from affecting the results as much. **PIOR: 2/1. CHR: 4/3.**

d. RL=30 deg/sec: Pilot technique was still improving and no degradation in performance was noted despite some delay being evident. **PIOR: 2/2. CHR: 3/3.**

e. RL=20 deg/sec: The pilot noted a small (±1/2 inch), slow (1 Hz) oscillation in the stick on the first run at this rate limit, but could not tell that there was any oscillation by looking outside or by feel (seat of the pants) and no degradation in performance was noted. No oscillations were noticed on the second approach. **PIOR: 4/2. CHR: 3/3.**

f. RL=15 deg/sec: Another small, slow oscillation was noted in the stick on the first run at this RATE LIMIT. This time, however, the delay was starting to become gross and pilot workload increased to compensate. **PIOR: 4/3. CHR: 4/4.**

g. RL=10 deg/sec: The small, slow oscillations were still noted in the stick at this RATE LIMIT. In addition, on the second run the flightpath angle was slightly steeper than for previous approaches, creating the need for a bigger pitch change at the flare. At this low RATE LIMIT, there was not quite enough pitch authority to make the roundout and a firm touchdown and bounce ensued. The evaluation pilot initiated a go-around and no further touchdowns occurred. A third approach was flown on which pilot made another large pitchup correction and could not take the input out in time. On this approach the aircraft softly skipped out of the desired box into the adequate box. Control was never in question. The major difference noticed on the second (and also, but to a lesser extent, on the third) approach was that the pilot stayed on the rate limit and for much longer periods (about 1 sec) than on the previous approaches where derate bounced off both sides of the rate limit continuously. **PIOR: 4/5/4. CHR: 4/7/5.**

Table G2
FLIGHT 2, PHASE 1

PILOT: Evensen			DATE: 1 Oct 96		FLIGHT No.: 2	Test Phase: 1
Run No.	K_s, Spring	K_ω, Frequency	Rate Limit (deg/sec)	PIOR	CHR	Comments:
1	1	1	Lear Jet	---	---	Warmup Landing
2	1	1	200.0	1	2	Warmup with rate limiting
3	1	1	200.0	1	3	Twice used elevator rate above 30 deg/sec, five times above 20 deg/sec elevator rate.
4	1	1	200.0	1	2	½ dot low on approach. Four times above 20 deg/sec elevator rate.
5	1	1	20.0	1	2	No turbulence. Hit rate limit 5 times.
6	1	1	20.0	2	3	Hit rate limit 8 times.
7	1	1	15.0	2	3	Sensed slight degradation in control. On rate limit 5% of time.
8	1	1	15.0	2	3	Only two significantly wide peaks on rate limit.
9	1	1	10.0	2	3	Small balloon on landing. On rate limit 15% of time.
10	1	1	10.0	2	3	On rate limit 10% of time.
11	1	1	7.5	2	3	On rate limit 30% of time.
12	1	1	7.5	2	3	On rate limit 30% of time.
13	1	1	5.0	2	3	On rate limit 50% of time. Pilot sensed rate limit on short final.
14	1	1	5.0	2	3	On rate limit 40% of time.
15	1	1	5.0	2	3	Aggressive rollin. On rate limit 40% of time.
16	1	1	5.0	4	8	Bounced landing. On rate limit 70% of time.
17	1	1	5.0	4-5	10	Safety trip at 10 feet above ground level. Excessive nose low. On rate limit 90% of time.
18	1	1	5.0	2	4	Minor compensation, had to lower gains when pilot felt rate limit. Light turbulence.

Notes:
1. K_s - stick spring constant multiplier
2. K_ω - stick natural frequency multiplier
3. PIOR - pilot induced oscillation rating
4. CHR - Cooper-Harper rating
5. --- no comments
6. General comments on Flight 2:

   a. As the rate limits were decreased, the most pronounced feeling was given to the pilot in the turn to final. There it could easily be felt that the pitch response was not as it should be. However, rolling out on final and stabilized on the ILS glideslope, very small corrections were made in the longitudinal axis. Even in the correction for the offset, the aircraft was kept on the glideslope with power only and very little deviation from the glideslope was induced. It should also be noted, that the pilot was told by the CALSPAN safety pilot not to pull too hard in the offset correction, not to exceed the allowable angle of attack of the Lear 25 system with the test flight control system engaged. As the rate limits were decreased, very little difference in the way the aircraft was flown was made and hence most of the CH and PIO ratings remain the same throughout the flight. However, on two of the landings (16 & 17) the pilot was distracted in the setup to landing by other aircraft flying in the pattern. This small distraction was enough to not be setup perfectly on glideslope when starting the correction for landing. Hence, when executing the correction for landing from the offset, the pilot also had to make a glideslope correction. This induced a need for

more rapid corrections, or higher pilot gains, and as soon as the gains were increased in the longitudinal axis the aircraft did not respond as expected. On landing No. 16 definite pilot induced oscillations were encountered in the last portion of the approach, but due to the low frequency of the oscillations the pilot was not able to determine if the PIO was divergent or not. A PIO rating of 4 was given. On landing No. 17 the same oscillations were induced but at a slightly higher altitude. However, the safety pilot took over the aircraft before touchdown due to a too nose low attitude that would not have been possible to correct with the low rate limit (5 degrees per second).

Table G3
FLIGHT 3, PHASE 1

PILOT: Major			DATE: 2 Oct 96		FLIGHT No.: 3	Test Phase: 1
Run No.	K_s, Spring	K_ω, Frequency	Rate Limit (deg/sec)	PIOR	CHR	Comments:
1	1	1	Lear Jet	---	---	Warmup landing.
2	1	1	200	1	5	---
3	1	1	200	1	2	Ontime history, no elevator rate peaks above 50 deg/sec, 7 peaks above 40 deg/sec.
4	1	1	30	2	3	Jerky motion. Noticeable limitation on pitch control effectiveness. On rate limit 15% of time.
5	1	1	30	2	3	Rate limit noticeable on forward stick motion. On rate limit 5% of time.
6	1	1	20	3	5	Adequate control for slow corrections. Hard to correct sink rate and pitch rate control. On rate limit 50% of time.
7	1	1	20	2	3	Sluggish in pitch. Bounce on landing. Appeared like there was a time delay in system. On rate limit 80% of time.
8	1	1	15	2	4	Sluggish. On rate limit 95% of time.
9	1	1	15	2	4	---
10	1	1	10	3	8	Tripped safeties. Significant delay in pitch. Oscillatory motion noticed.
11	1	1	10	2	4	Delay in pitch and decreased responsiveness. On rate limit 98% of time.
12	1	1	5	3	8	High workload and landed in adequate box but landing wasn't soft. Safety pilot took for go-around.
13	1	1	5	3	8	Go-around executed. Sluggish in pitch. Undesired and uncorrectable sink rate.
14	1	1	5	3	9	High compensation in pitch axis due to time delay. Delay in response was too big. Hard landing.

Notes:
1. K_s - stick spring constant multiplier
2. K_ω - stick natural frequency multiplier
3. PIOR - pilot induced oscillation rating
4. CHR - Cooper-Harper rating
5. --- no comments
6. General comments on Flight 3:

a. Nominal (200 deg/sec): No noticeable deficiencies. Pilot was able to fly the task crisply and precisely PIOR 1, CHR 2 overall for the combined runs.

b. 30 deg/sec: Noticed rate limiting immediately when pilot applied nosedown trim. When pilot trimmed nose down, he would occasionally bump the stick forward and would see a time delayed jerk in the aircraft response. The time delay was small but perceptible. This led to the aircraft not having as crisp of a response as pilot would have liked; PIOR 2, CHR 3, overall.

c. 20 deg/sec: Time delay getting longer. Controls showed some sluggishness. Setup on run not stable leading to slow airspeed on final, thus landing early; PIOR 2, CHR 3 overall.

d. 15 deg/sec: Time delay getting longer. Now seeing a marked increase in workload. Increased workload included closer analysis of glidepath and more rapid longitudinal inputs. Sluggishness continued to increase; PIOR 2, CHR 4 overall.

e. 10 deg/sec: Getting a little tougher to fly. Run No. 9 tripped off on second turn in task. The aircraft was slow and started to exceed the safety angle-of-attack limit. Setup was not stable in airspeed/glidepath on the run. Run No. 10 seemed to be more representative and repeatable; PIOR 2, CHR 4 overall.

f. 5 deg/sec: All three tries failed to complete task. However, aircraft was controllable. Pilot would have been able to land it from a straight-in. Very sluggish pitch response made precise glidepath control during maneuvering impossible. No tendencies for PIO were seen on runs 11 and 12. The frequency of the response seemed slow enough to prevent any PIOs. On run 13, the aircraft automatic safety features tripped off during a glideslope correction at 50 feet above ground level. The potential for PIO may have been present, however the aircraft kicked itself off after one-half of a cycle. More runs at 5 deg/sec may help to define its PIO susceptibility. PIOR 3, CHR 8 overall.

7. Overall comments:

a. The low apparent frequency response of the controls seemed to aid in preventing PIO. A faster apparent frequency response may increase the susceptibility to PIO. Also, a larger longitudinal gain may increase the magnitude of the undesirable motions, thus seeing more pronounced effects as rate limits were lowered.

b. For the task and control system being tested, we may find the PIO rating scale too course. Since we are not seeing any PIO until the task is not doable, the scale has only three ordinates compared to the CH scale which has six ordinates to describe the doable task.

Table G4
FLIGHT 4, PHASE 2

PILOT: Peters			DATE: 3 Oct 96	FLIGHT No.: 4		Test Phase: 2
Run No.	K_s, Spring	K_ω, Frequency	Rate Limit (deg/sec)	PIOR	CHR	Comments:
1	1.0	1	200.0	2	3	Safety trip occurred prior to touchdown. Few rates above 40 deg/sec.
2	1.0	1	200.0	2	3	Had to control speed through correction. Several rates above 40 deg/sec.
3	1.0	1	200.0	2	5	Adequate performance. Light Turbulence and tail wind present. Above 40 deg/sec elevator rate 8 times.
4	1.0	1	7.5	4	5	Bounced landing. On rate limit 60% of time.
5	1.0	1	7.5			Safety trip at initial correction of offset.
6	1.0	1	7.5	3	5	Slight bounce. Never cycled stick back and forth. On rate limit 80% of time.
7	1.4	1	7.5	3	5	High and fast at start of correction. Did notice oscillations and considered them undesired motion. Stick cycles were faster.
8	1.4	1	7.5	3	5	Landed after C-18. Considerable pilot compensation and bounced out of desired box. Heavy stick force noticed turning final. No oscillations noticed. A good size correction was required to get desired box.
9	1.8	1	7.5	3	4	Increased turbulence made it difficult to hold speed. Seemed less oscillatory than run 7, but oscillations still present. Desired performance with moderate workload.
10	1.8	1	7.5	4	7	Small oscillation. Fast at start of maneuver. "Out of there" PIO 100% prior to touchdown.
11	1.8	1	7.5	3	5	Heavy stick force which the pilot commented kept him from putting in lots of stick.
12	2.2	1	7.5	2	4	Very high stick force. Oscillatory motions did not get away from pilot. Desired performance and moderate workload. Rate limits mostly in one direction. Stick forces very high.
13	2.2	1	7.5	3	4	Bigger bobbles. Delay was bugging pilot. Desired performance with moderate workload. Less time in rate limit. Very heavy stick forces.
14	0.6	1	7.5	4	5	Small and higher frequency stick motion. Pilot working harder to keep stick under control. Adequate performance. More time on rate limit. Light to moderate turbulence.
15	0.6	1	7.5	4	5	Desired performance with considerable workload. Light to moderate turbulence.
16	1.0	1	7.5	4	5	Adequate performance. Slow oscillation noticed in the rate of descent (low amplitude and frequency). PIO prior to touchdown.

Notes: 1. K_s - stick spring constant multiplier
2. K_ω - stick natural frequency multiplier
3. PIOR - pilot induced oscillation rating

4. CHR - Cooper-Harper rating
5. General comments on Flight 4:

   a. The ratings showed a very slight improvement for the heavier sticks. Qualitatively, the pilot thought that the heavier the stick, the less tendency he felt he had to cause oscillations. In the turn to final, the stick forces were noticeably heavier or lighter, but on final they were not as noticeable.

Table G5
FLIGHT 5, PHASE 2

PILOT: Peters		DATE: 4 Oct 96		FLIGHT No.: 5		Test Phase: 2
Run No.	K_s, Spring	K_ω, Frequency	Rate Limit (deg/sec)	PIOR	CHR	Comments:
1	1	1.0	200.0	1	3	Warmup. Smooth as glass air. Max elevator rate used was 25 deg/sec.
2	1	1.0	200.0	1	2	Warmup
3	1	1.0	7.5	1	5	Low pilot gains because air was so calm. Landed long
4	1	1.0	7.5	2	3	---
5	1	1.0	7.5	2	3	Wobble when crossing landing box.
6	1	1.4	7.5	3	4	Bigger wobble.
7	1	1.4	7.5	2	3	More responsive, but not a big difference.
8	1	1.8	7.5	2	3	Firm touchdown. Not a noticeable difference
9	1	1.8	7.5	3	4	Little more motion.
10	1	2.2	7.5	2	3	Workload barely minimal.
11	1	2.2	7.5	2	3	Steeper at the end of the landing. No noticeable change. Light to moderate turbulence.
12	1	0.6	7.5	2	3	Heavier, more delay.
13	1	0.6	7.5	3	4	Big wobble, affected performance, but not that much.
14	1	0.4	7.5	2	3	Stick feels heavier and slower, but not much difference in performance.
15	1	0.4	7.5	2	3	---

Notes:
1. K_s - stick spring constant multiplier
2. K_ω - stick natural frequency multiplier
3. PIOR - pilot induced oscillation rating
4. CHR - Cooper-Harper rating
5. --- no comments
6. General comments on Flight 5: The ratings showed no trends. Qualitatively, the pilot thought that the nominal stick was about the best, but changes in stick natural frequency had no effect on the tendency he felt he had to cause oscillations. In the turn to final, the pilot noted that lower stick natural frequencies made the stick forces appear heavier.

Table G6
FLIGHT 6, PHASE 2

PILOT: Major		DATE: 4 Oct 96		FLIGHT No.: 6		Test Phase: 2
Run No.	K_s, Spring	K_ω, Frequency	Rate Limit (deg/sec)	PIOR	CHR	Comments:
1	1.0	1	200.0	3	5	Warmup. Low on final. 8 elevator rate peaks over 50 deg/sec.
2	1.0	1	200.0	2	4	Warmup. Annoying tendency on correction.
3	1.0	1	7.5	3	5	Pulled to limit and held several times. Under corrected on initial turn. Short of desired.
4	1.0	1	7.5			Tripped the safeties on initial correction.
5	1.0	1	7.5	2	4	Undesirable motions. Definite delay in pitch. Also sluggish in pitch.
6	1.0	1	7.5	3	5	Bounced landing. Sideslip reached 5 degrees.
7	1.4	1	7.5	4	8	Convergent oscillation noticed. Stick was more sluggish.
8	1.4	1	7.5			Go around due to C-130 on runway.
9	1.4	1	7.5	3	5	Light turbulence. No oscillation.
10	1.8	1	7.5	4	4	Light turbulence. Large sink rate correction required. Very low frequency oscillation (PIO) noticed in the rate of descent. Frequency of oscillation was about 8 sec.
11	1.8	1	7.5	3	6	Pilot worked very hard on sink rate control. Very sluggish stick. Adequate performance.
12	2.2	1	7.5	4	5	Again, low frequency oscillation in rate of descent.
13	2.2	1	7.5	4	4	Workload increased due to high stick force and slow response. It was luck that the landing was in the desired zone. Sluggishness makes for considerable workload.
14	0.6	1	7.5	4	4	Weird combination of stick force and elevator responsiveness.
15	0.6	1	7.5	4	4	Low frequency PIO is still there.

Notes:
1. K_s - stick spring constant multiplier
2. K_ω - stick natural frequency multiplier
3. PIOR - pilot induced oscillation rating
4. CHR - Cooper-Harper rating
5. Additional comments on Flight 6: Saw a gradual decrease in flying qualities as "spring" was increased. From point 6 on, I saw a slow speed PIO in glidepath. The oscillation had a period of about 7-10 seconds. As the spring constant got heavier, the oscillation grew in magnitude.

When the spring constant was decreased below the nominal (run 14 & 15), the glidepath oscillation was still noticed, however, it was subtle. This leads me to believe the PIO was there for the nominal stick (run 3-5) but went unnoticed.

Workload slowly increased as spring constant increased. It wasn't until point 11 that I would have called the workload extreme. However I noticed that initial conditions for the task affected workload greatly.

Stick inputs for the heavier springs were slow but intense because of the slow aircraft response to a longitudinal control input. Going form the heaviest spring to the lightest spring (pt 13 to 14) showed a dramatic change in compensation techniques. At the light spring, stick input was very jerky. The jerkiness was similar to stick pumps often seen in an aircraft flair, but continuous and intense.

showed a dramatic change in compensation techniques. At the light spring, stick input was very jerky. The jerkiness was similar to stick pumps often seen in an aircraft flair, but continuous and intense.

e. Again, on this flight, the PIO sale wasn't fine enough to breakout the gradual decrease in flying qualities. In fact, the CHR had a lot of noise in them. To reduce noise in the CHR, I plan to call all runs that have undesired control response as adequate or worse, regardless of where and how I touchdown. This I believe will lead to a little less noise in the ratings as well as possibly finer detail broken out.

Table G7
FLIGHT 7, PHASE 2

PILOT: Major		DATE: 7 Oct 96		FLIGHT No.: 7		Test Phase: 2
Run No.	K_s, Spring	K_ω, Frequency	Rate Limit (deg/sec)	PIOR	CHR	Comments:
1	1	1.0	200.0	1	3	Warmup. High on glideslope. On oscillatory tendency.
2	1	1.0	200.0	1	3	Warmup. Little more correction.
3	1	1.0	7.5	2	4	Undesired motions, but didn't compromise task. Moderate work load, desired performance.
4	1	1.0	7.5	4	7	Pilot initiated go-around. Little PIO. Setup was high and hard to correct. Go-around just prior to touchdown.
5	1	1.0	7.5	2	4	Undesirable motions, but didn't compromise task. Little sluggishness. Some delay in system noticed.
6	1	1.0	5.0	2	4	Worked harder than last time. Undesirable motions, but didn't compromise task. Moderate compensation.
7	1	1.4	5.0	4	5	Large bounce. Some oscillations noticed, though they were hard to see (very small amplitude). Task affect considered/ considerable compensation. Sluggish on stick.
8	1	1.4	5.0	4	5	Oscillations noticed. Desired performance with considerable compensation.
9	1	1.8	5.0	4	5	Stick appeared more sensitive and jerkier. No increase in workload. Pilot lowered his gains. Adequate performance.
10	1	1.8	5.0	4	4	Slight oscillation.
11	1	0.6	5.0	4	5	Considerable pilot compensation. 7-10 second period PIO noticed in the glideslope.
12	1	0.6	5.0	4	5	Again oscillation in the sink rate. Jerky inputs to dampen the motion. No perceptible change in stick.
13	1	0.4	5.0	4	6	Stick seemed to float back and forth with very little pilot input. Increased compensation. Stick forces were a little light.
14	1	0.4	5.0	4	6	Stick PIO, couldn't see the oscillation outside the aircraft. More annoying than anything else.
15	1	1.0	5.0	4	4	Oscillation in glideslope. No stick oscillation. Between moderate and considerable compensation.

Notes: 1. K_s - stick spring constant multiplier
2. K_ω - stick natural frequency multiplier
3. PIOR - pilot induced oscillation rating
4. CHR - Cooper-Harper rating
5. Additional comments on Flight 7: Both 7.5 deg and 5 deg/sec rate limits showed low frequency sink rate oscillations. However 5 deg/sec showed it more consistently. The 7.5 deg/sec rate limit was

5. General comments on Flight 7:

a. Both 7.5 deg and 5 deg/sec rate limits showed low frequency sink rate oscillations. However 5 deg/sec showed it more consistently. The 7.5 deg/sec rate limit was more dependent on initial conditions for the task. Note that the air was smooth today for the entire sortie.

b. Changes in stick frequency showed no increase in the aircraft PIO frequency and amplitude. The PIO stayed low amplitude at an approximate period of 7-10 seconds. Changes in stick frequency did show a decrease in handling qualities. The higher frequency sticks had marginally higher handling qualities rating. The lower frequency sticks were marginally higher than the nominal stick. Initial condition seemed to greatly affect the ratings, thus 1 radian per second and higher were very close in workload.

c. At K_ω=0.4, a stick PIO was encountered that did not translate to perceivable aircraft motion. The stick seemed to float back and forth with a 1-2 second period. This oscillation was seen in level flight as well as during the maneuvering. This stick PIO greatly increased workload.

d. Initial conditions were important. If stabilized on airspeed and glideslope at task initiation, the task appeared easier to do. Thus, to see changes in controls configuration, exact initial conditions should be avoided.

Table G8
FLIGHT 8, PHASE 2

PILOT: Evensen		DATE: 7 Oct 96		FLIGHT No: 8		Test Phase: 2
Run No.	K_s, Spring	K_ω, Frequency	Rate Limit (deg/sec)	PIOR	CHR	Comments:
1	1.0	1	200.0	1	3	Warmup. Max elevator rate used was 40 deg/sec.
2	1.0	1	200.0	1	3	Warmup. Adequate performance, misjudged the aim point. The CHR of 3 was assigned because the pilot felt the failure to achieve desired performance was the result of his misjudgment, not the aircraft handling qualities.
3	1.0	1	7.5	1	3	Feels like some rate limit, but doesn't compromise task.
4	1.0	1	7.5	2	3	Feels more nose heavy.
5	1.4	1	7.5	1	3	A little better.
6	1.4	1	7.5	1	3	---
7	1.8	1	7.5	2	4	Sluggish in pitch and was hard to correct.
8	1.8	1	7.5	2	4	Even worse. Hard to make rapid corrections.
9	2.2	1	7.5	2	4	Not as stiff a stick. Not a significant difference.
10	2.2	1	7.5	2	4	Very stiff stick. Pilot felt he couldn't correct as much.
11	0.6	1	7.5	2	4	Light stick. Felt like there was lots of freeplay. Too loose and felt "strange".
12	0.6	1	7.5	2	5	Desired performance with more than moderate compensation.
13	1.0	1	7.5	2	4	Undesirable motions. Rate limiting was sensed.

Notes:
1. K_s - stick spring constant multiplier
2. K_ω - stick natural frequency multiplier
3. PIOR - pilot induced oscillation rating
4. CHR - Cooper-Harper rating
5. --- no comments
6. Additional comments on Flight 8: The best stick to fly, just based on feel of the stick, was the nominal stick. However, with a slight increase in the stick spring constant, slightly better CHRs were given because the task was performed better. With even more increase in the stick spring constant, the stick felt too stiff and it was difficult to make small rapid corrections to the glideslope.

With the lighter stick spring constants, the aircraft felt very loose in the longitudinal axis. It felt like the stick had too much freeplay and it almost felt like some control of the aircraft was lost.

Table G9
FLIGHT 9, PHASE 3

PILOT: Evensen		DATE: 7 Oct 96		FLIGHT No.: 9		Test Phase: 2
Run No.	K_s, Spring	K_ω, Frequency	Rate Limit (deg/sec)	PIOR	CHR	Comments:
1	1	1.0	200	1	2	Still air. Peak elevator rate used was 15 deg/sec.
2	1	1.0	200	1	2	30 deg/sec elevator rate used.
3	1	1.0	5	1	2	Felt a little rate limit. Would not realize the difference in available rate limit in a blind test. Only one place just prior to touchdown where elevator wasn't within 80 % of rate limit.
4	1	1.0	5	2	3	A little low on initial Setup. Data suspect.
5	1	1.4	5	1	3	Stick felt a little better than the last run. Less time on rate limit than the two previous runs.
6	1	1.4	5	1	3	Felt better than the nominal stick. More time on rate limit than previous run.
7	1	1.8	5	2	3	Didn't feel quite as good as the previous run. Spent more time holding the stick on the rate limit. More correction required by the pilot.
8	1	1.8	5	2	3	Misjudged altitude.
9	1	0.7	5	3	4	Stick felt more sluggish. Didn't like the stick as much as the nominal stick. Consistently on rate limit.
10	1	0.7	5	3	4	Not really responsive in flair. Hard to correct for pitch.
11	1	0.4	5	2	4	Stick felt "weird", like it was bouncing. Otherwise felt stable.
12	1	0.4	5	4	7	Could feel rate limit. Small PIO present. Workload required improvement. Very persistent on rate limit just prior to touchdown.
13	1	2.2	5	3	5	Felt much better than the lower stick frequencies. Bounced on landing.
14	1	2.2	5	2	5	Same comment as 13. No bounce this time. Less persistently on rate limit.

Notes:
1. K_s - stick spring constant multiplier
2. K_ω - stick natural frequency multiplier
3. PIOR - pilot induced oscillation rating
4. CHR - Cooper-Harper rating
5. Additional comments on Flight 9: The best stick was the one where the stick natural frequency was increased slightly (1.4 times nominal). With this stick the aircraft felt more responsive. With increasing stick natural frequency the stick almost felt as if the spring constant was increased.

With a decrease in the stick natural frequency, the stick felt sluggish and it almost amplified the feeling of a slow response from the aircraft.

Table G10
FLIGHT 10, PHASE 3

PILOT: Evensen		DATE: 9 Oct 96		FLIGHT No.: 10		Test Phase: 3
Run No.	K_s, Spring	K_ω, Frequency	Rate Limit (deg/sec)	PIOR	CHR	Comments:
1	1.0	1.0	200	2	3	Warmup. Light turbulence. Two peaks over 40 deg/sec on data traces.
2	1.0	1.0	200	2	3	Warmup. Light turbulence. Three peaks over 30 deg/sec.
3	1.4	1.0	15	2	4	One dot low on setup. Hit rate limit. Stick felt looser than previous run. Work load moderate
4	1.4	1.0	15	3	5	Light turbulence. Not quite the responsiveness the pilot wanted at end of flare. Adequate performance with considerable workload.
5	1.0	1.0	5	5	7	Oscillations were present and growing in amplitude. Adequate with maximum tolerable compensation.
6	1.0	1.0	5	2	4	Safety pilot took aircraft on final. The oscillation found in run 5 was not present this time. No gross corrections on final. Moderate compensation.
7	1.0	1.4	5	3	6	Definitely could sense the rate limit. Task was compromised. It was hard to tell if there was an oscillation. Stick felt lighter than the previous stick. Adequate performance with extensive compensation.
8	1.0	1.4	5	3	6	Sloppier stick, noticeably worse than previous stick. Workload higher than pervious run. Adequate performance achieved.
9	1.0	1.0	15	2	4	Elevator rate didn't hit the rate limit as much as on the previous run. Stick felt stiffer. Undesirable motion was not as bad as previous run.
10	1.0	1.0	15	4	7	Aggressive correction required at end of offset. Oscillation present, but not divergent.
11	1.0	1.4	15	2	4	Not as much rate limiting. Some undesirable motion, but didn't compromise task. No perceived change from run 10.
12	1.0	1.4	15	2	4	Little undesirable motion, didn't compromise task. Moderate compensation. Stick change had no effect in task performance.
13	1.4	1.0	5	4	8	Definitely requires improvement. Considerable compensation required for control. Rate limiting definitely felt. Small stick corrections at the end. Was able to stop the oscillations that occurred. Forces were too heavy. Once in flare, the forces were to heavy to correct. Biggest PIO yet.
14	1.4	1.0	5	4	9	Bounce on landing. Unable to make small rapid corrections. Able to damp out the oscillations that occurred. Major compensation and intense concentration required.

Notes: 1. K_s - stick spring constant multiplier
2. K_ω - stick natural frequency multiplier
3. PIOR - pilot induced oscillation rating
4. CHR - Cooper-Harper rating

4. CHR - Cooper-Harper rating
5. Additional comments on Flight 10:

   a. On this flight, the winds were moderate in amplitude and gusting (5-10 knots). The workload on all landings was considerably higher than on any of the other flights due to the winds. The results may not be totally repeatable due to the gusty winds. However, it was seen that noting any difference between a change in the stick natural frequency and stick spring constant was very difficult and no effort was made to investigate what stick was programmed into the flight control system. Just flying the task, sometimes the increase in stick natural frequency was felt as a increase in the stick spring constant and vice versa.

   b. Specific comments for each stick and rate limit combination are given in the table above.

Table G11
FLIGHT 11, PHASE 3

PILOT: Peters		DATE: 10 Oct 96		FLIGHT No.: 11		Test Phase: 3
Run No.	K_s, Spring	K_ω, Frequency	Rate Limit (deg/sec)	PIOR	CHR	Comments:
1	1.0	1.0	200	2	3	Warmup. A couple of elevator rate peaks over 20 deg/sec.
2	1.0	1.0	200	1	2	Warmup. A couple of peaks over 30 deg/sec.
3	1.0	1.4	5	3	5	A little bit of delay in stick response. Slow aircraft response. Desired performance, but workload more than moderate. Some long holds on rate limit.
4	1.0	1.4	5	2	3	Quite a delay. Sluggish. A lot worse than the previous. Not as persistently on rate limit as previous run.
5	1.0	1.0	5	3	5	Pulled power too soon. Landing wasn't smooth. Didn't notice the delay quite so much.
6	1.0	1.0	5	2	4	Noticed a little delay. Little bobble in airspeed control. Just slightly better than previous configuration.
7	1.4	1.0	5	2	3	A little heavier stick forces on the turn. Slightly better than previous configuration. Slight bobble and slight delay. Wasn't working as hard on this landing as previous ones.
8	1.4	1.0	5	2	3	Worked the flare. Little compensation. Noticeably better than before. Airplane helps to be smooth.
9	1.4	1.0	15	2	3	Noticeably lighter stick forces. Less delay and more responsive. Nicer stick forces. Noticeably better.
10	1.4	1.0	15	2	3	Open loop. Little bobbles and some delay. Lighter stick forces. Generally nicer stick on final.
11	1.0	1.0	15	2	3	A little heavier stick force. Not quite as good, more bobble.
12	1.0	1.0	15	2	3	Not much difference from previous stick. Heavier stick force prevents flare. No significant difference versus other configurations.
13	1.0	1.4	15	2	3	Slightly nicer. Lighter stick force and more responsive. Control response was right away. Slightly less bobble and better in the flare.
14	1.0	1.4	15	2	3	Got slow and had a firm touchdown. Not much difference between last two runs. Didn't flare as much. Not sure it is the stick.

Notes:
1. K_s - stick spring constant multiplier
2. K_ω - stick natural frequency multiplier
3. PIOR - pilot induced oscillation rating
4. CHR - Cooper-Harper rating
5. Additional comments on Flight 11: The rate limit on the first three sets of test points was low enough and caused enough degradation of handling qualities that differences were seen for the different sticks. The last three sets were not degraded enough to have significant differences caused by the sticks.

Table G12
FLIGHT 12, PHASE 3

PILOT: Major		DATE: 10 Oct 96		FLIGHT No.: 12		Test Phase: 3
Run No.	K_s, Spring	K_ω, Frequency	Rate Limit (deg/sec)	PIOR	CHR	Comments:
1	1.0	1.0	200	1	3	Warmup. A couple of elevator rates over 40 deg/sec.
2	1.0	1.0	200	1	3	Warmup. Light turbulence in base turn. Landed a little off centerline. Was more aggressive in turn.
3	1.0	1.4	5	2	4	Apparent delay in system made sink rate control harder. Stick felt heavier. May have been a small oscillation. Held stick at rate limit for 1.5 seconds at one point.
4	1.0	1.4	5	2	4	No oscillation. Some undesired motion with the delay. Moderate compensation. Heavier stick than run 1 with some apparent delay. Held stick at rate limit for 1.5 seconds at one point.
5	1.0	1.0	5	3	5	Small premature oscillation in base turn. Light turbulence. Configuration appeared more oscillatory. Pilot compensation was to be jerky on inputs. Bigger overshoots. Stick felt lighter than runs 3 and 4. Held stick at rate limit for 1.2 seconds at one point.
6	1.0	1.0	5	4	5	Considerable oscillations in glideslope. Comfortable stick, but jerky. Held stick at rate limit for 1.2 seconds at one point.
7	1.4	1.0	5	4	6	Trouble with oscillations in flare. Big bounce on landing. Gross oscillations were the worst seen so far. Stick felt heavy and there was apparent pitch delay. Held stick at rate limit for 1.8 seconds at one point.
8	1.4	1.0	5	4	6	Same large oscillations. Used throttle to setup. Extensive compensation ("working hard"). Heavy stick with time delay = oscillations. Held stick at rate limit for 2 seconds at one point.
9	1.4	1.0	15	4	5	Stick felt faster but still heavy. Still some time delay (smaller than before). Slightly heavier on stick forces. Considerable compensation. Some oscillations, but better than last stick. Held stick at rate limit for 0.8 second at one point.
10	1.4	1.0	15	4	5	Oscillation on base turn. Desired box, but considerable compensation. Slightly jerky stick.
11	1.0	1.0	15	4	6	Lighter stick, fast, but more delay. Little more delay than last stick. Working hard on glideslope (extensive) to damp oscillation. One dot high at correction. Held stick at rate limit for 0.5 second at one point.
12	1.0	1.0	15	4	6	Light turbulence, stronger than before. Highest frequency oscillation seen yet. Very objectionable. Worse than stick in runs 7 and 8. Held stick at rate limit for 0.8 second at one point.
13	1.0	1.4	15	3	5	Good on stick sensitivity. Little time delay. Crisp, little jerkiness.
14	1.0	1.4	15	2	4	Minor but annoying def. Little delay, but still annoying. Less delay than previous stick.

Notes: 1. K_s - stick spring constant multiplier
2. K_ω - stick natural frequency multiplier
3. PIOR - pilot induced oscillation rating
4. CHR - Cooper-Harper rating

Table G13
FLIGHT 13, PHASE 3

PILOT: Peters		DATE: 10 Oct 96	FLIGHT No.: 13		Test Phase: 3	
Run No.	K_s, Spring	K_ω, Frequency	Rate Limit (deg/sec)	PIOR	CHR	Comments:
1	1.0	1.0	Base Learjet	2	5	Warmup. Small undesired motion.
2	1.0	1.0	Base Learjet	3	5	Warmup. Sloppy feel. Undesired motion. Hit 60 deg/sec once, 50 deg/sec three times, 40 deg/sec four times.
3	1.0	1.4	10	2	5	3 KIAS off airspeed-adequate performance. Undesired motion, but not oscillatory. Moderate compensation/ workload. Delay causes sluggish response. Not as sloppy, but more sluggish. Skipped out of box.
4	1.0	1.4	10	3	3	Minimal compensation. Undesirable motion didn't affect performance. Better performance out of this stick
5	1.0	1.0	10	4	7	Light-moderate turbulence. Undesired motion requiring pilot compensation. One bounce to a go-around. Pitch control not able to arrest gust effects. Controllable but needed big inputs. Big pitch rate change just prior to touchdown.
6	1.0	1.0	10	3	6	More sensitive stick, but worse performance. Oscillation was large amplitude in pitch but could be damped out. Corrected to the desired box. Extensive compensation. Was on the rate limit more with this stick.
7	1.4	1.0	10	3	4	Some undesirable motion. Worked hard for desired performance. Light to moderate turbulence. Heavier stick slowing down input (limiting). Airplane sluggish to input. Did not push airplane to limit.
8	1.4	1.0	10	3	4	Some undesired motion. Little oscillation on glideslope. Putting input in and taking it out was major form of compensation. Better than last stick. Reduced sensitivity was good.
9	1.4	1.0	200	2	3	Stick still heavy. Minimal-moderate workload. Aircraft responded better. Aircraft less sluggish. Some undesired motion.
10	1.4	1.0	200	2	4	Seemed lighter stick forces (even more so than previous run). Pilot was moving hand faster. Small undesired motion resulted in moderate compensation. Hand jerking around more.
11	1.0	1.0	200	2	3	Pretty nice configuration. Turbulence induced bobble. Between minimum-moderate compensation to get better performance. Improvement over runs 9/10.
12	1.0	1.0	200	2	3	Minor undesired motion. Minimal side of work load. Hand not jerking about to fly plane.
13	1.0	1.4	200	2	3	Light to moderate turbulence. No difference in stick from runs 11/12.
14	1.0	1.4	200	2	3	Pretty nice.

Notes:
1. K_s - stick spring constant multiplier
2. K_ω - stick natural frequency multiplier
3. PIOR - pilot induced oscillation rating
4. CHR - Cooper-Harper rating

5. General comments on Flight 13:

a. The rate limit on the first three sets of test points was low enough (combined with the afternoon turbulence) to cause degradation in handling qualities but the problem was really in control power available, not PIO. The last three sets were not degraded enough to have significant differences in performance caused by the sticks.

b. A discussion with Russ Easter after the flight brought out the fact that, for many of the configurations flown, the pilots knew that there were significant problems with the airplane. The CHRs do not reflect how bad the pilots really thought the airplane was but instead were driven by task performance and perceived workload.

Table G14
FLIGHT 14, PHASE 3

PILOT: Evensen			DATE: 11 Oct 96	FLIGHT No.: 14		Test Phase: 3
Run No.	K_s, Spring	K_ω, Frequency	Rate Limit (deg/sec)	PIOR	CHR	Comments:
1	1.0	1.0	Base Learjet	1	2	Warmup. No undesired motion. Could make small abrupt changes without exciting undesired motion. Two elevator rate peaks above 30 deg/sec.
2	1.0	1.0	Base Learjet	1	2	Warmup. Easy to make small corrections. One peak above 40 deg/sec, five above 30 deg/sec.
3	1.0	1.4	10	1	3	Little stiffer stick. Not as responsive. Could make relatively big corrections. Overshot on final. Could not feel rate limit. No tendency to hold stick on rate limit.
4	1.0	1.4	10	1	3	No sustained rate limit. Corrections at end not quite as easy as first two runs.
5	1.0	1.0	10	1	3	Hard to see difference. Stick a litter lighter. Stick feels better, but no real change in performance. Very little time spend holding at rate limits.
6	1.0	1.0	10	1	2	Rate limit at flare, not as responsive as first one. Really minor.
7	1.4	1.0	10	1	3	Little undesired motion if pilot increased gain. Stick heavier, more like runs 3 and 4.
8	1.4	1.0	10	1	3	Hard time discerning between different runs.
9	1.4	1.0	200	1	3	Small input at end resulted in undesired motion. Can't tell difference between previous stick.
10	1.4	1.0	200	2	3	Just outside desired box (still pretty good flying). The CHR 3 was assigned by the pilot because he felt he was the cause of the performance degradation. Stick a bit heavier (need to fly more closed loop than before). "Not quite the responsiveness I wanted."
11	1.0	1.0	200	1	3	Small corrections caused the airplane to respond well. Stick more responsive. Still hard to discern differences.
12	1.0	1.0	200	1	2	Flies nice. Like stick better than runs 9/10. Responds nicely all the way down.
13	1.0	1.4	200	1	3	At flare—make small rapid corrections. Not quite as good as previous configuration. No undesirable motion.
14	1.0	1.4	200	1	3	No difference.

Notes:
1. K_s - stick spring constant multiplier
2. K_ω - stick natural frequency multiplier
3. PIOR - pilot induced oscillation rating
4. CHR - Cooper-Harper rating

5. General comments on Flight 14:

a. Again it was hard to tell the difference between the changes in the stick constant and changes in the stick natural frequency. Since the test was performed blind to pilot, he tended to fly a little higher gain in the offset landing task than on the three first flights. This was to check if there was any undesirable aircraft motions induced by increasing pilot gains. This increase in pilot gain is reflected in the CHRs. Almost no undesirable aircraft motions were discovered on any of the landings. Specific comments for each combination of rate limiting and stick characteristic is given in the above table.

Table G15
FLIGHT 15, PHASE 3

PILOT: Major		DATE: 11 Oct 96		FLIGHT No.: 15		Test Phase: 3
Run No.	K_s, Spring	K_ω, Frequency	Rate Limit (deg/sec)	PIOR	CHR	Comments:
1	1.0	1.0	Base Learjet	2	4	Warmup. Stick too responsive (light). Predictable, no apparent delay.
2	1.0	1.0	Base Learjet	2	4	Warmup. No time delay. Good response. Stick high frequency response. Light turbulence.
3	1.0	1.4	10	2	4	Heavier stick + same frequency = better. No delay. Predictable. Longest occurrence of holding at the rate limit was 0.8 sec.
4	1.0	1.4	10	2	5	Heavier stick. Responsive. No time delay. Might have floated trying to flare. Light turbulence.
5	1.0	1.0	10	2	4	Jerky motion for last three sticks. Light turbulence. Longest occurrence of holding at the rate limit was 0.5 sec.
6	1.0	1.0	10	2	4	Stick jerky. High flare. Felt in control. Light turbulence.
7	1.4	1.0	10	4	5	Heavier stick, less in control. Not as much jerky motion. Considerable compensation. Longest occurrence of holding at the rate limit was 1.2 sec.
8	1.4	1.0	10	4	6	More aggressive. Heavy sluggish stick. Extensive compensation.
9	1.4	1.0	200	4	6	Light pulsing of stick. More responsive than last stick. Still heavy stick. Extensive compensation.
10	1.4	1.0	200	4	7	Light turbulence. Pitch sensitivity with some delay.
11	1.0	1.0	200	4	8	Lighter stick than last time. Stick seems to float a little bit. Short period PIO in flare.
12	1.0	1.0	200	4	7	Not as bad as last time, but still working hard.
13	1.0	1.4	200	4	6	PIO attend. Better than last stick.
14	1.0	1.4	200	4	5	Stick floated.

Notes:
1. K_s - stick spring constant multiplier
2. K_ω - stick natural frequency multiplier
3. PIOR - pilot induced oscillation rating
4. CHR - Cooper-Harper rating

APPENDIX H
LESSONS LEARNED

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LESSONS LEARNED

During the course of the HAVE GRIP flight test program, there were several lessons learned which are necessary and valuable for additional testing of pilot induced oscillation (PIO) caused by rate limiting.

1. Most of the offset landing tasks were flown early in the morning to avoid gusty winds and provide consistent, repeatable results. However, because of the calm winds, the pilots were able to fly the offset landing task almost open loop, thereby not experiencing PIO. The few flights flown later in the day when the winds were more gusty, showed that pilots had to use higher elevator rates and thereby experienced more PIOs. However, whether or not a PIO was experienced on a given approach was very dependent upon the amount of gusty winds and turbulence. This makes any results difficult to duplicate. A better way of forcing the pilot into higher gains would be to incorporate a gust generator into the variable stability system. This way, if flown in the early morning, the task would be repeatable and still generate the increased pilot gain required to facilitate PIO.

2. Possible solutions to the low rate limit problem include: using the gust generator mentioned above; an up-and-away close formation task on a maneuvering target (or any other higher gain, operationally representative task); a simulated aircraft without such good dynamics; or a higher order flight control system so that the elevator actuators will still be working hard even if the pilot is relatively low gain. The idea is to get the degradation in handling qualities to occur at a much higher rate limit.

3. With the very small differences between test points, neither the PIO nor the Cooper-Harper rating scale was fine enough to make any distinctions between test points. Well documented pilot comments were the best discriminator between test configurations. These worked best when comparisons were made between consecutive test points.

4. The HAVE GRIP flight test program should have been designed so that the test pilots were not aware of the expected results of the study. All project pilots were involved with the test planning and knew that rate limiting was a variable being tested. In all phases, preconceived notions regarding the test points could have affected stick compensation, pilot comments, and assigned ratings. When the pilot knew what to look for, it was easier to tailor the findings and comments to the expected results.

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Abbreviation	Definition	Unit
A/C	Aircraft	---
AFB	Air Force Base	---
AGL	above ground level	---
CH	Cooper-Harper	---
CHR	Cooper-Harper Rating	---
deg	degree(s)	---
derate	elevator rate	deg/sec
F_{es}	longitudinal stick force	lb
FRR	Flight Readiness Review	---
IAF	Israeli Air Force	---
ILS	instrument landing system	---
KIAS	knots indicated airspeed	---
K_s	stick spring constant multiplier	---
K_ω, K_w	stick natural frequency multiplier	---
kts	knot(s)	---
Lear II	CALSPAN Variable Stability Learjet Model 25, registration number N102VS	---
lb	pound(s)	---
MSL	mean sea level	ft
NM	nautical mile	---
PAR	Program Assessment Review	---
PIO	pilot induced oscillation	---
PIOR	pilot induced oscillation rating	---
PTI	programmed test inputs	---
q	aircraft pitch rate	deg/sec

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS (Concluded)

Abbreviation	Definition	Unit
q_{max}	rate limiting	deg/sec
RL	elevator rate limit	deg/sec
RNoAF	Royal Norwegian Air Force	---
RTO	responsible test organization	---
Rad	radian	---
S/N	serial number	---
s	Laplacian operator	---
sec	second(s)	---
TPS	Test Pilot School	---
VSS	variable stability system	---
USAF	United States Air Force	---
δ_e	elevator deflection	deg
δ_{ec}	elevator deflection commanded	deg
δ_{es}	longitudinal stick deflection	in

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